4. Housing Design and Layout

4.1 INTRODUCTION

This chapter discusses housing design and requirements for air cleaning units in which filters are installed in man-entry housings. Large-volume air supply and exhaust requirements may be met by a number of individual filter-blower installations operating in parallel, by a single central system, or by a combination of both. Individual filter-blower systems, shown in Fig. 4.1, have the advantages of (1) greater flexibility from the standpoint of system modification; (2) little interference with operations during filter replacement, because individual units can be shut down without affecting the remaining systems; (3) good overall control of ventilation in the event of malfunction, fire, or accident to one or a few of the individual units; and (4) easy system balancing. On the other hand, batteries of individual filter-blower systems are more costly to build, operate, and maintain than a single central system of the same capacity. If individual systems discharge to individual stacks, there is also the risk of flow reversal (with the danger of contamination spread to occupied areas), when one or more fans are out of service and others continue to operate. Flow reversal during a fire in some part of the building could also result in an inadvertent and undesirable air feed to the fire, which has occurred on some occasions.

4.1. Battery of individual filter-blower systems exhausting fume hoods of a radiochemical laboratory.

Filters of a central system may be arranged in banks in a large filter house or in a multiple single-filter array in which a number of filters are installed between common supply and exhaust headers, as Fig. 4.2 shows. Such a multiple single-filter array must be located in a room that can be sealed off from adjacent operating, storage, and equipment areas and that lends itself to easy decontamination. In no case should a multiple single-filter array be located in an open attic or building space where problems of contamination spread could result if a filter were dropped during a change operation. The multiple single-filter arrangement has the advantages that all filters can be installed at a convenient height for replacement, and personnel do not have to enter what may be a highly contaminated filter house to change filters. The design of the individual filter installation in a multiple single-filter array is similar to that of other single-cell installations discussed in Chap. 6. Careful alignment of filter inlet and outlet connections is essential. If these connections are even slightly out of alignment, a poor seal will result, and the condition will worsen if there is system pulsation and vibration. Inlet and outlet duct axes must coincide within $\pm$ $^1/_{16}$ in.; a minimum of 2 in. (preferably 4 in.) should be allowed between filter units for access and ease of maintenance. When tape-sealed open-face filters are used, the spacing between units should be at least 6 in. to allow the workman to manipulate the tape and achieve proper adhesion. Aisle space in front and back is desirable to permit the inspection of seals. Tape-sealed connections are prone to fail, even under normal operating conditions; however, because the tape peels, these connections are not recommended.

In bank systems, a number of open-face filters are installed in parallel on a single mounting frame in a

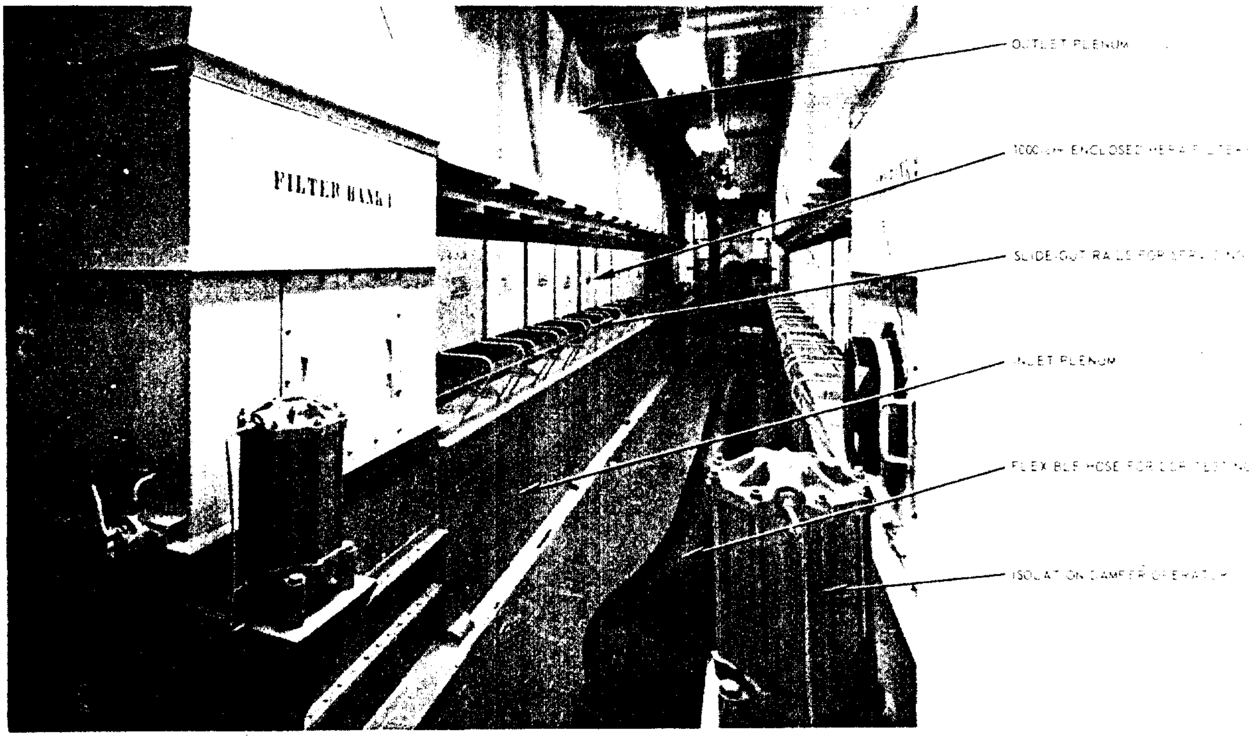

Fig. 4.2. **Multiple single-filter central exhaust system installed in a Zone II contamination area.** Courtesy Atomic Energy of Canada, Limited, Chalk River Laboratory.

single housing. Because banks are the more common type of large multiple-filter installation, the remainder of this chapter is devoted primarily to their design and construction, including spatial arrangement, mounting frames, housings, instruments, and testing. Although the discussion relates primarily to exhaust filter systems, most of it is equally applicable to clean-room installations and other supply-air systems that employ high-efficiency filtration. Figure 4.3 shows how large some of these installations can be, particularly in laminar-flow clean rooms and in some of the earlier central-exhaust systems of nuclear facilities. Installations containing nearly a thousand 1000-cfm HEPA filters in a single bank have been built in the past, but banks larger than 30,000-cfm nominal capacity (i.e., thirty 1000-cfm filters) are no longer recommended for nuclear exhaust or cleanup service because of the difficulties of control (in the event of emergencies), maintenance, and testing. For exhaust and cleanup systems larger than 30,000-cfm capacity, segmentation of the system into two or more parts of equal airflow capacity, with each part in an individual housing installed in parallel, is recommended. Isolation valves on each housing are desirable for ease of system control, for isolation of individual units during an emergency, and for maintenance or testing.

Bank systems have the advantages of lower unit construction cost, lower unit operating cost, and lower space requirements when compared with multiple single-filter systems. For example, the 36,000-cfm multiple single-filter array in Fig. 4.2 occupies about 600 ft^2 of floor space and a volume of approximately 9000 ft^3, whereas a bank system of equal capacity would occupy less than 200 ft^2 of floor space and a volume of less than 1400 ft^3. The operating cost of such a multiple single-filter system may be 20 to 30% higher than that of an equivalent bank system because of friction and dynamic losses in the plenums and in the individual filter inlets and outlets.

4.2 COMPONENT INSTALLATION

Proper installation of HEPA filters, adsorber cells, and demisters is critical to the reliable operation of a high-efficiency air cleaning system. Factors that must be considered in the design of such installations include:

1. structural rigidity of mounting frames;
2. rigid and positive clamping of components to the mounting frame;
3. careful specification of and strict adherence to close tolerances on alignment, flatness, and surface condition of component seating surfaces;

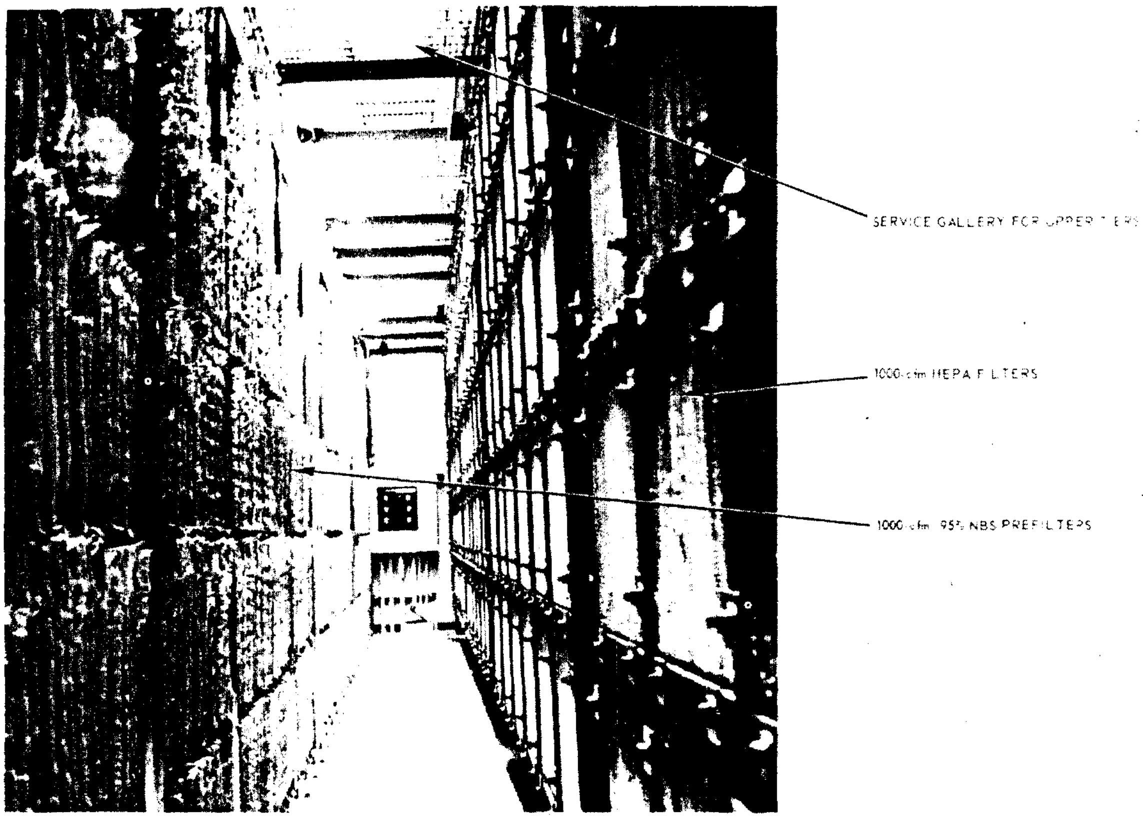

Fig. 4.3. Prefilter and HEPA filter banks of a large horizontal-flow laminar-flow clean room. Courtesy National Aeronautics and Space Administration, Greenbelt Unmanned Spaceflight Center.

4. welded-frame construction and welded seal between the mounting frame and the housing;
5. ability to inspect the interface between components and mounting frame during installation;
6. adequate spacing between components in the bank;
7. adequate spacing in the housing for men to work.

The components and mounting frame should form a continuous barrier between the contaminated zone and the clean zone of the system; any hole, crack, or defect in the mounting frame or in the seal between component and frame which permits bypassing will result in leakage of contaminated air into the clean zone and a decrease of system effectiveness. A mounting frame that is not sufficiently rigid can flex so much during operation, particularly under abnormal conditions, that leaks may develop in HEPA filters clamped to the frame (due to differential flexing of the filter case relative to the mounting frame). Cracks may also be opened between the filters and the frame, between frame members (due to weld cracking or fatigue), or between the frame and the housing. Insufficient attention to maintenance provisions in the original design can increase operating costs and reduce the reliability of the system. Once the system is installed, defects are difficult to locate, costly to repair, and may even require rebuilding the system.

The out-of-date practices of simply stacking filters (adsorbers) in a rectangular opening (using duct tape to seal gaps between filters and between filters and the opening) and of installing them in lightly constructed honeycomb mounting frames of the type shown in Fig. 4.4 are not acceptable for nuclear service. Joints between mounting frame members and between the mounting frame and the housing wall should be sealed by welding. Duct tape, mastics, resilient sealants (such as RTV silicone), and other "applied" sealing materials invariably fail from exposure to alternating heat, cold, moisture, dry air, vibration, or combinations of these conditions, which are usually encountered in high-efficiency exhaust and air cleanup systems; such materials must not be used in critical systems. Such sealing methods are prohibited in ESF systems.[1] The honeycomb frame is permissible for prefilters and duct-entry installations of

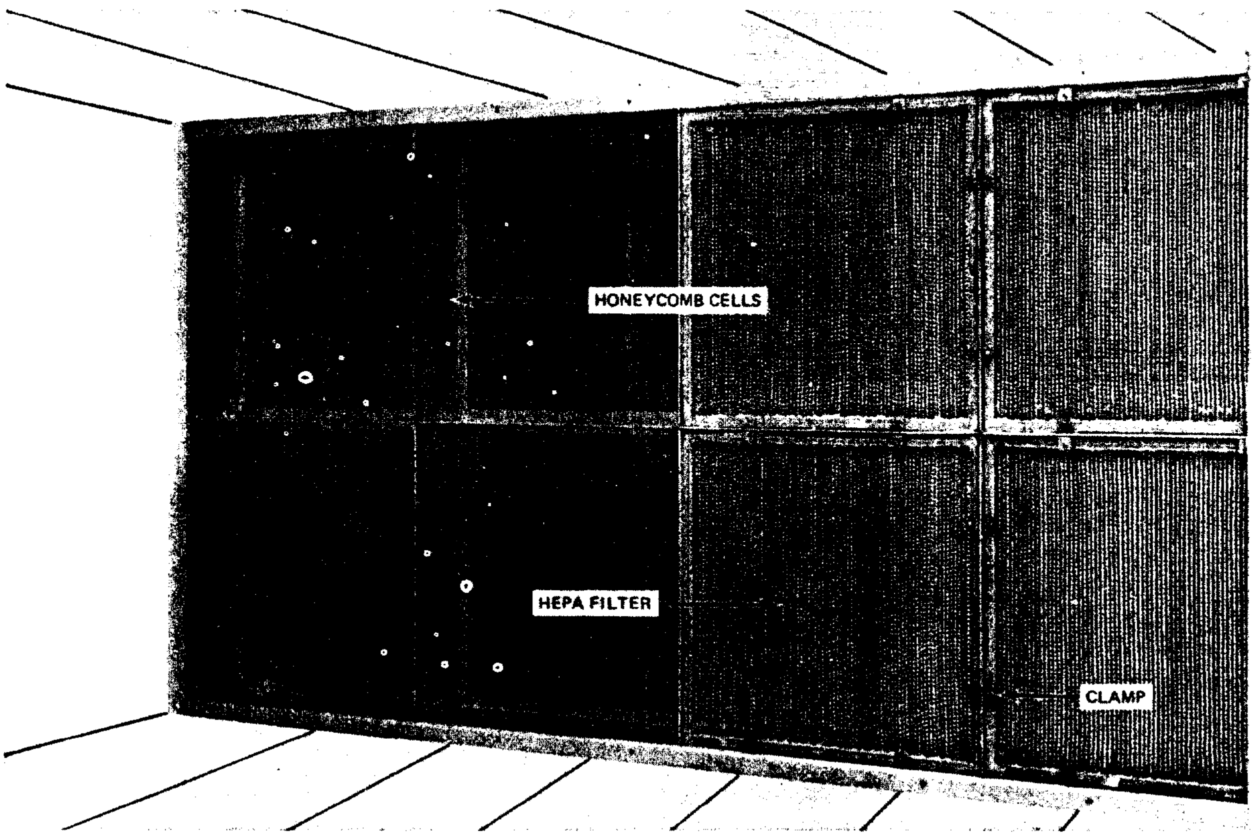

Fig. 4.4. Honeycomb mounting frame made up of individual filter cells bolted or riveted together. Note the caulked joints and the light-duty filter mounting frame and clamping devices. Mounting frames of this type are not suitable for installing HEPA filters in nuclear exhaust applications.

common air filters, but the stacked-and-taped method should not be employed for either HEPA filters or prefilters under any circumstances.

4.3 HEPA FILTER, ADSORBER CELL, AND DEMISTER MOUNTING FRAMES

Mounting frames for HEPA filters and other critical components should be all-welded structures of carbon or stainless steel structural shapes, plate, or heavy cold-formed sheet. Carbon steel frames should be painted or coated for corrosion resistance. Galvanized steel is not recommended because of welding difficulties and because the zinc coating does not give adequate protection in environments that may be encountered in a contaminated exhaust system. Aluminum is not recommended. Because of the high cost of surface preparation, inspection, and rework usually incurred in obtaining high-quality vinyl and epoxy coatings, stainless steel is often the best and most economic choice in radiochemical plant applications. Suitable mounting frame materials include:

- carbon steel shapes and plate, ASTM A36,[2] A499;[3]
- carbon steel structural tubing, ASTM A500;[4]
- carbon steel sheet, ASTM A245, grade D;[5]
- stainless steel shapes, ASTM A479, type 304L, class C, annealed and pickled;[6]
- stainless steel plate, ASTM A240, type 304L, hot-rolled, annealed, and pickled;[7]
- stainless steel sheet, ASTM A240, type 304L, annealed and pickled, 2D or 2B finish.[7]

Information relating to fabrication includes:

"Specification for the Design, Fabrication, and Erection of Structural Steel for Building," *Manual of Steel Construction*, American Institute of Steel Construction, New York, 1970.

Light-Gage Cold-Formed Steel Design Manual, American Iron and Steel Institute, New York, 4th ed., 1962,

AWS D1.1-72, *AWS Structural Welding Code*, American Welding Society, Miami, 1972.

O. W. Blodgett, *Design of Welded Structures*, James F. Lincoln Arc Welding Foundation, Cleveland, 1966.

4.3.1 Structural Requirements

The mounting frame is a statically indeterminate lattice that generally consists of a set of full-length members spanning the height or width of the bank (whichever is shorter), connected by cross members that are slightly shorter than the width of individual filter (adsorber) units. The frame may be considered as an array of simply supported, uniformly loaded beams for design purposes. Experience has shown that to obtain adequate frame rigidity, these beams (frame members) should deflect no more than 0.1% of their length under a loading equivalent to 1.5 times the maximum dirty-filter pressure drop across the bank. This loading is determined from the equation

$$W = 0.036(1.5)\,\Delta p\; S, \tag{4.1}$$

where

0.036 = conversion factor, in.wg to psi;
W = uniform beam loading, lb/in.;
Δp = pressure drop across bank, in.wg;
S = center-to-center spacing of filters on bank, in.

Assuming a center-to-center spacing of 26 in. for 24- by 24-in. filters, Eq. (4.1) reduces to

$$W = 1.404\,\Delta p\,. \tag{4.2}$$

The value determined from Eq. (4.2) can be used in standard beam equations[8] to determine the minimum moment of inertia required. Knowing the minimum moment of inertia required for the member, the size and shape can be selected directly from the tables of structural shape properties given in the AISC *Manual of Steel Construction*,[9] or can be determined by calculating the moment of inertia of a built-up or cold-formed section. For ASTM A36 steel, the standard beam equations reduce to

$$\text{major frame members, } I = \frac{\Delta p\, L^3}{1.59\times 10^6}\,, \tag{4.3}$$

$$\text{cross members, } I = \frac{\Delta p}{149}\,, \tag{4.4}$$

where

I = minimum moment of inertia required, in.^{4};
Δp = maximum dirty-filter pressure drop across bank, in.wg;
L = length of member, in. (cross members assumed to be 22 in. long).

In addition to flexural strength, the frame for an exhaust or air cleanup filter system should also be capable of withstanding a shock loading of at least 3 psi across the bank without exceeding the elastic limit of the frame material. In most cases, members calculated using Eqs. (4.3) and (4.4) will meet this requirement; nevertheless, they should be checked. The section moduli (S values) given in Part I of the AISC *Manual of Steel Construction*[9] are then compared with the minimum values obtained from the following equations:

$$\text{major frame members, } S = \frac{13L^2}{f_a}\,, \tag{4.5}$$

$$\text{cross members, } S = \frac{6290}{f_a}\,, \tag{4.6}$$

where

S = section modulus, in.^{3};
f_a = maximum allowable fiber stress, psi;
L = length of member, in. (cross members assumed to be 22 in. long).

For ASTM A36 steel, these equations reduce to

$$\text{major frame members, } S = 0.000361L^2 \tag{4.7}$$

$$\text{cross members, } S = 0.175\,. \tag{4.8}$$

For built-up and cold-formed members, the minimum S value calculated from these expressions is compared with the value for the member calculated from the formula

$$S = \frac{I}{c} \tag{4.9}$$

where

S = section modulus, in.^{3};
I = moment of inertia of the section, in.^{4};
c = distance from neutral axis of member to extreme fiber, in.

If the S values obtained from the AISC manual or calculated by using Eq. (4.9) are greater than the values calculated from Eqs. (4.5) through (4.8) (as applicable), the members selected are satisfactory.

4.3.2 Mounting Frame Configuration

There are three basic types of mounting frame construction: (1) face-sealed, in which the filter seals to the outermost surfaces of the frame members by means of gaskets glued to the front surface or to the flange around the face of the filter unit, as Fig. 4.5 shows; (2) pocket, in which the filter fits into an opening of the frame and seals, by means of a gasket glued to the face flange of the filter unit, on an inner flange, as Fig. 4.6 shows; and (3) drawer, in which the filter (or adsorber cell) fits through an opening and seals, by means of a gasket glued to the back of the face plate of the filter or adsorber cell, to the outermost surfaces of the frame members, as Fig. 4.7 shows. The latter configuration is an adaptation of the case used for type II adsorber cells[10] and, for filters, requires a specially designed metal-case HEPA filter as shown in Fig. 4.7. The face-sealed configuration is generally recommended for conventional-design HEPA filters and type I adsorber cells.[10] Pocket-type mounting frames, although satisfactory in some instances, are not recommended for the following reasons. (1) Because access to the recessed filter-sealing surfaces is often limited, removal of weld slag and spatter is difficult and often incomplete, thus preventing proper seating and sealing of filter gaskets. (2) If wood-cased filters are used and dimensions of the pocket openings are tight, swelling of the wood cases as a result of moisture may prevent easy removal of used filters. (3) Filter-sealing surfaces and gaskets are obscured during filter installation. Face-sealed mounting frames may occupy slightly more space in the filter housing than pocket frames, but they require less material and less welding, thereby presenting fewer opportunities for leakage.

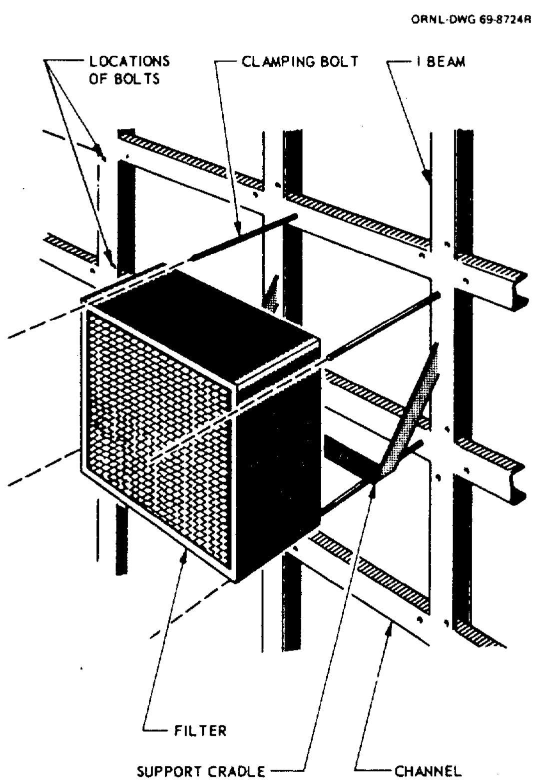

Fig. 4.5. **Face-sealed mounting of HEPA filter.** Note eight-bolt clamping and support cradle. Frame is all-weld construction, using structural I-beams and channels.

A minimum face width of 4 in. is recommended for major and cross members of face-sealed HEPA filter frames. This allows 1-in.-wide filter-seating surfaces to compensate for any misalignment of the filter during installation, and allows a 2-in. space between filters, horizontally and vertically, to give adequate room for handling (personnel replacing contaminated filters will probably have to wear double gloves), for using power tools or torque wrenches during filter change, and for manipulating a test probe between units. Although mounting frames made from members as narrow as $2\frac{1}{2}$ in. are often used, the slight increase in material cost and building space required by the use of wider frame members will result in easier access and thereby lower cost of maintenance.

Face-widths of frame members for installing type I (pleated-bed) adsorber cells are the same as those for HEPA filters. Face-widths of frame members for installing type II (tray-type) adsorber cells may be narrower, since handles are provided on the front of the trays to facilitate installation. To provide for interchangeability of cells of different manufacture, IES CS-8 recommends the following mounting frame dimensions for the installation of type II cells (see IES CS-8 for standard cell dimensions):[10]

Openings: 6.37×24.188 in. (+0.063 in., − 0 in.)

Space between openings: vertical, 2.5 in. minimum; horizontal, 2 in. minimum

Figure 4.8 shows a built-up all-welded type II adsorber cell mounting frame made from rectangular structural tubing; note that a structure is required

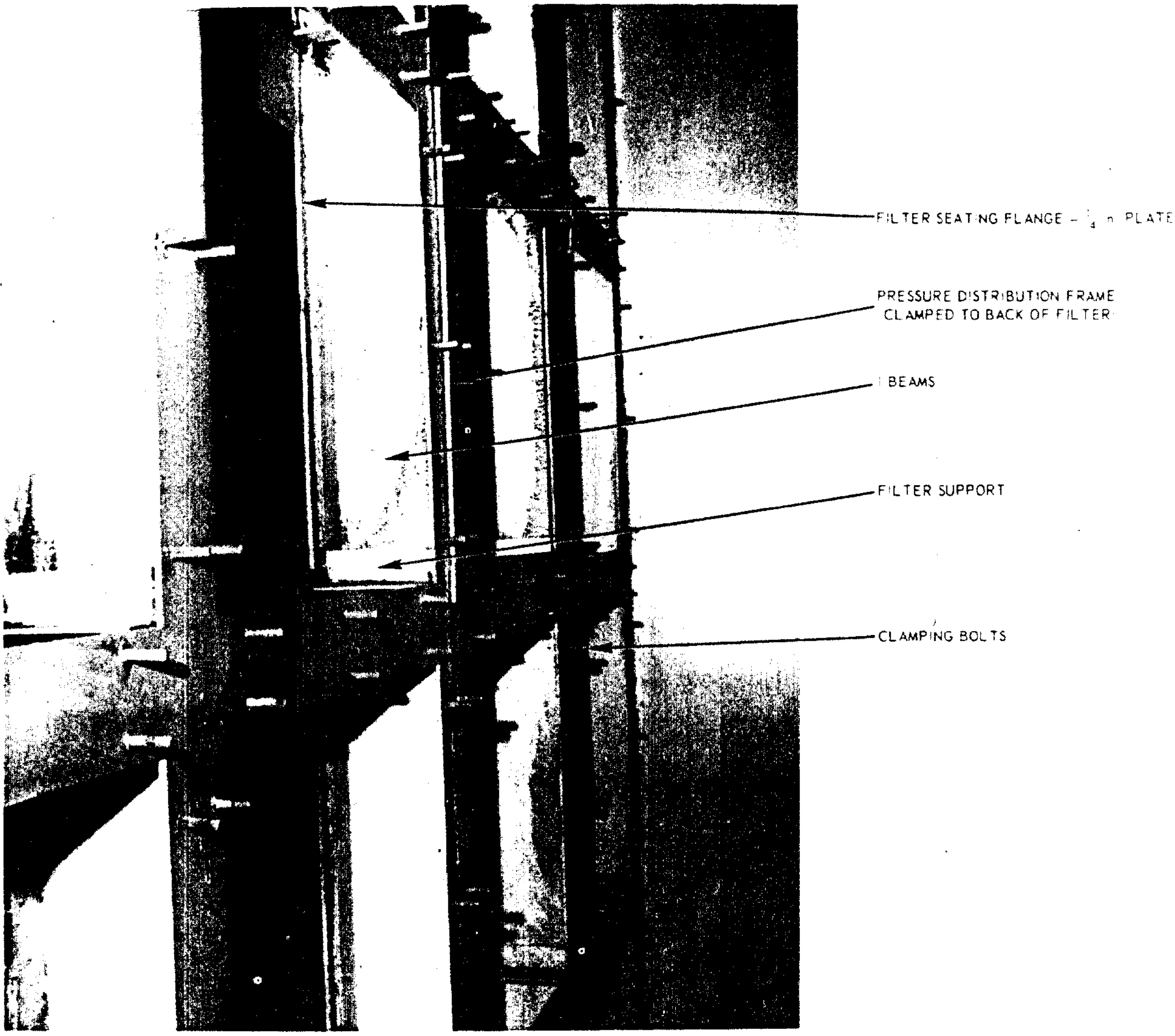

Fig. 4.6. Built-up pocket-type filter mounting frame for 500-cfm HEPA filters.

behind the frame openings to support the weight of the cells (approximately 100 lb each). Because the length of type II cells may be different for each manufacturer, the support structure should be deep enough to take a cell up to 32 in. long to permit interchangeability of cells of different manufacture.

Satisfactory mounting frames may be made from rolled structural shapes, rectangular structural tubing, reinforced plate, or brake- or die-formed heavy gage (No. 14 U.S. gage minimum, No. 11 U.S. gage recommended) sheet metal. Figure 4.9 shows a HEPA filter frame made from 4- by 4-in. I-beams that meets all structural requirements. Minimum-cost rolled structural shapes for building mounting frames are given in Table 4.1. Square structural tubing frames for HEPA filters should be made from rectangular tubing having a face width of at least 4 in.; structural tubing frames for type II adsorber cells may have narrower face widths (Fig. 4.8). Figure 4.10 shows the front and rear of a face-sealed HEPA filter frame made from a single piece of $^3/_8$-in. plate welded into a 4- by 6-in. I-beam "picture frame" and reinforced on the back with bar to provide the required structural rigidity. Note that the reinforcing bars are skip-welded to the plate to minimize distortion during welding but that a continuous seal weld is provided between the face of the frame and the "picture frame." Openings in this frame were plasma-torch cut and then finished by machining. This design

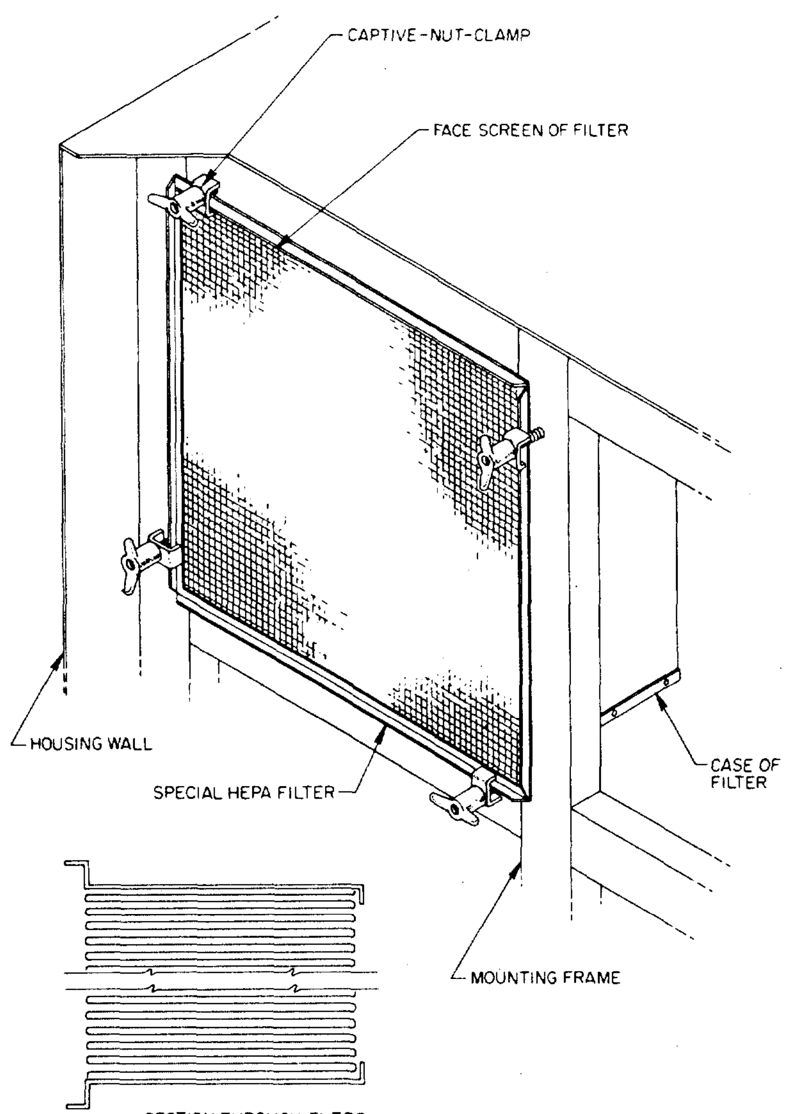

Fig. 4.7. Section of drawer-type mounting frame for HEPA filter showing details of clamping and specially designed HEPA filter. Courtesy Flanders Filter Corp.

has the advantage of requiring less material than a structural-shape frame or square tubing frame. The fact that it is made from a single piece of plate, with no welding on the face, eliminates frame-member misalignment and heat-of-welding distortion problems. Figure 4.11 shows an all-welded HEPA filter frame built up from die-formed sheet-metal members.

4.3.3 Frame Fabrication

Filter mounting frames should be shop-fabricated insofar as practicable, because it is nearly impossible to avoid misalignment, warping, and distortion in field fabrication. Shop fabrication is less costly than field fabrication and permits better control over assembly, welding, and dimensional tolerances. Care must be taken to avoid twisting or bending of the completed frame during handling, shipping, and field installation. For proper performance and ease of maintenance of installed filters, dimensional and surface-finish tolerances must be tight and rigidly enforced. Table 4.2 gives minimum tolerances for the installed frame. Welds on the filter-seating side of the frame must be ground flat, smooth, and flush.

The inert-gas-shielded metal-arc (GMA) welding process and inert-gas-shielded tungsten-arc (GTA) welding process are recommended for shop and field fabrication. The GMA process is particularly well adapted to field work because it is fast, gives a reasonably good quality of weld when made by a qualified welder under good conditions, and has low heat input.[11] Seal welds between adjoining members and between the frame and housing should be full-penetration welds and must be made from the air-entering side. Only welders qualified in accordance with the AWS *Structural Welding Code* or Sect. IX

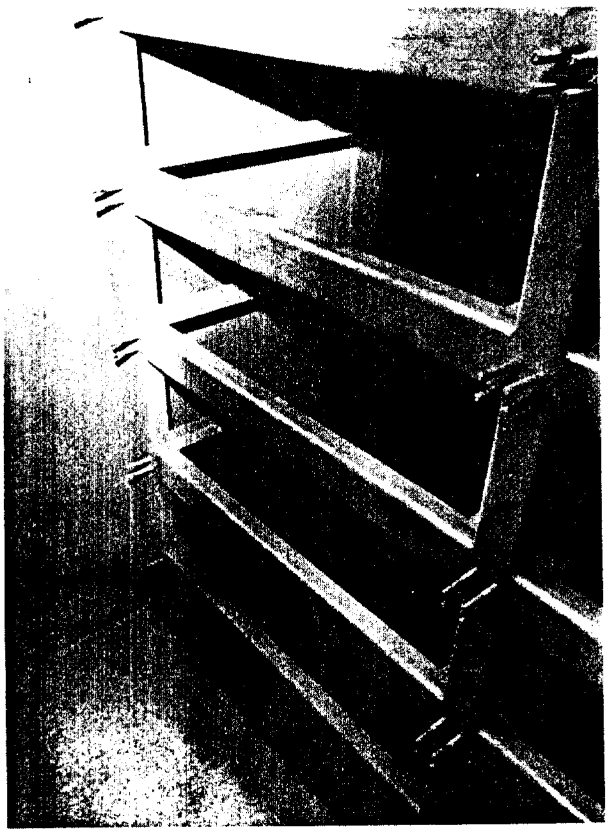

Fig. 4.8. Type II adsorber cell mounting frame made from rectangular structural tubing. Note cell support structure.

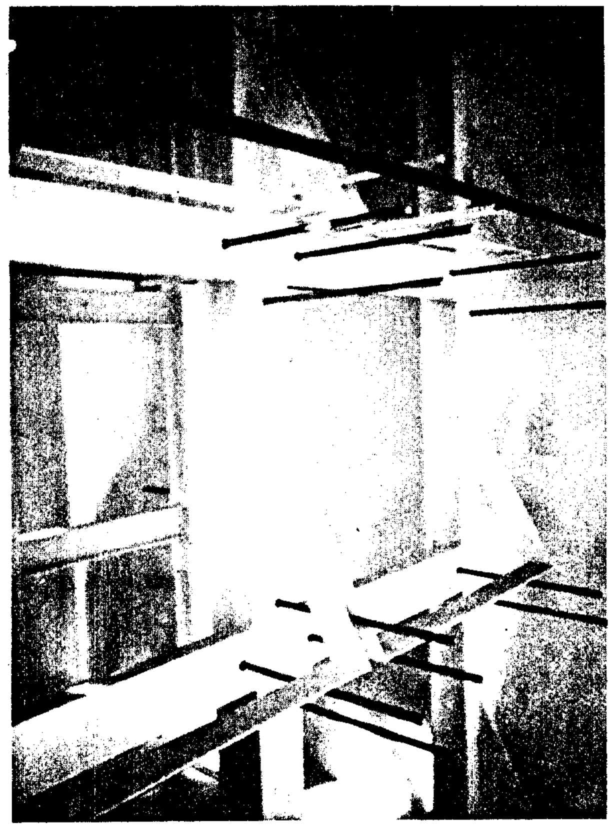

Fig. 4.9. HEPA filter mounting frame made from rolled structural shapes (4- by 4-in. I-beams).

Table 4.1. Minimum-cost structural members for HEPA filter and adsorber mounting frames
Maximum pressure drop to 12 in.wg

No. of 1000-cfm units high	Principal member,[a] I-beam			Cross member channel (span = 22 in.)	
	Span[b]	Size (in.)	Pounds per foot	Size (in.)	Pounds per foot
2	4 ft 8 in.	4 × 4 M	13	4 × $1\frac{3}{4}$	5.4
3	6 ft 10 in.	4 × 4 M	13	4 × $1\frac{3}{4}$	5.4
4	9 ft 0 in.	4 × 4 M	13	4 × $1\frac{3}{4}$	5.4
6	13 ft 4 in.	6 × 4 B	16	4 × $1\frac{3}{4}$	5.4
8	17 ft 8 in.	8 × 4 B	10	4 × $1\frac{3}{4}$	5.4
10	22 ft 0 in.	10 × $4\frac{5}{8}$	25.4	4 × $1\frac{3}{4}$	5.4

[a]Principal members should span the shortest dimension of the bank.
[b]Span=[(number of filters)(26)+4] in.

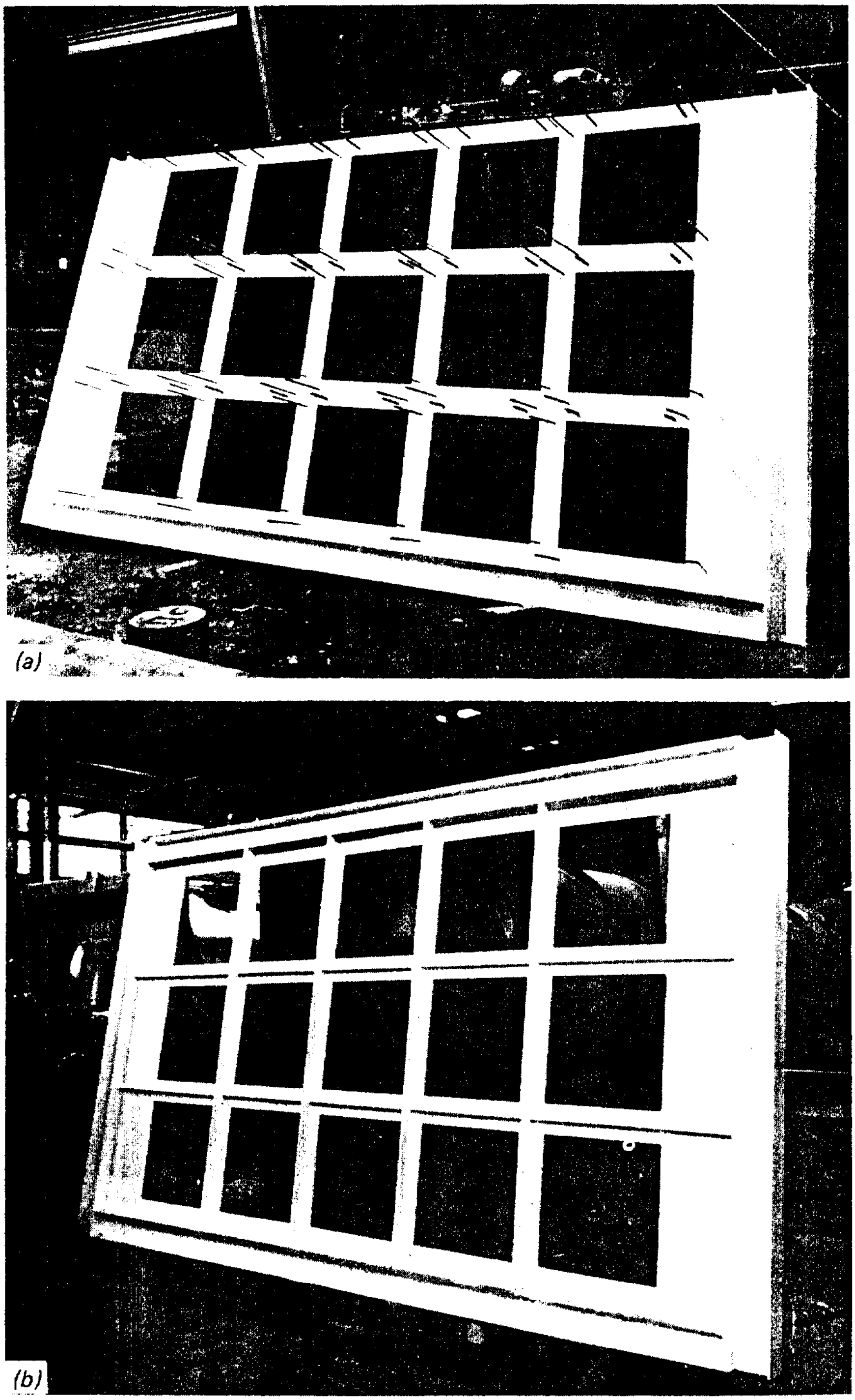

Fig. 4.10. HEPA filter mounting frame made from a single $^3/_8$-in. plate during fabrication in manufacturer's shop. Openings are torch-cut, then finished by machining. "Picture frame" made from I-beams reinforces housing in addition to providing rigidity to frame itself. (*a*) Front; (*b*) rear; note reinforcing bars skip-welded to single plate. Courtesy CTI-Nuclear, Inc.

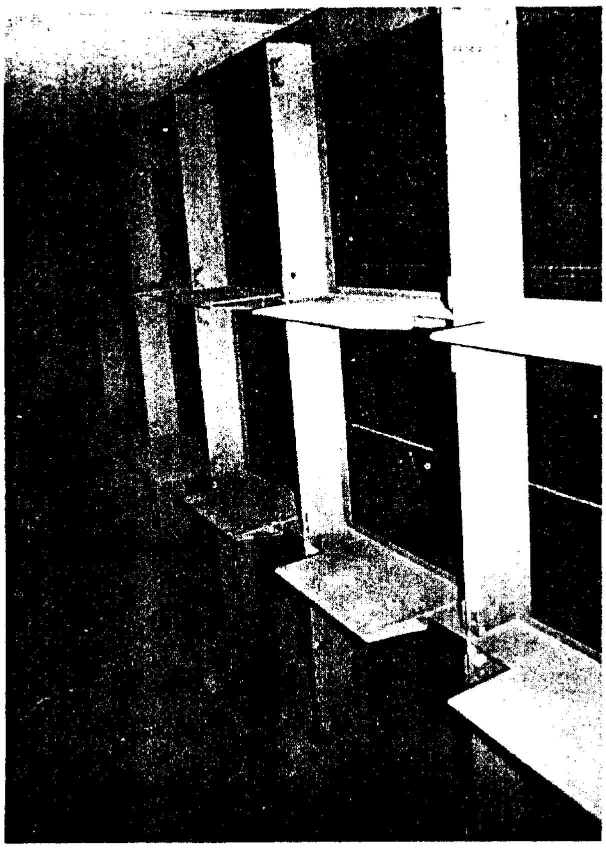

Fig. 4.11. All-welded HEPA filter frame made from die-formed sheet-metal members. Note pocket-type configuration and filter rests beneath openings. Filters are arranged in two 6-wide by 3-high arrays, one above the other with a permanent work gallery between.

Table 4.2. Recommended tolerances for HEPA filter and adsorber mounting frames

Alignment	Perpendicularity: maximum offset of adjoining members, $^1/_{64}$ in./ft or $^1/_{16}$ in., whichever is greater
	Planarity of adjoining members: $^1/_{64}$ in. maximum offset at any point on the joint
Flatness	Each filter surface shall be plane within $^1/_{16}$ in. total allowance
	Entire mounting fixture shall be plane within $^1/_2$ in. total allowance in any 8- by 8-ft area
Dimensions	Length and spacing of members shall be true within +0, $-^1/_{16}$ in.
Surface finish	Filter seating surfaces: 125 μin. AA, maximum, in accordance with USA Standard B46.1; pits, roll scratches, weld spatter, and other surface defects shall be ground smooth after welding, and ground areas shall merge smoothly with the surrounding base metal; waviness not exceeding $^1/_{16}$ in. in 6 in. is permissible as long as the overall flatness tolerance is not exceeded

of the *ASME Boiler and Pressure Vessel Code*[12] should be permitted to make welds on HEPA filter and adsorber mounting frames. Both seal and strength welds should be visually inspected by a qualified inspector under a light level of at least 100 ft-c on the surface being inspected. In addition, liquid penetrant or magnetic particle inspection (whichever is applicable for the base material being inspected) of the seal welds between frame members is recommended. Guides for visual, liquid penetrant, and magnetic particle inspection are given in Articles 6, 7, and 9, respectively, of Sect. V of the *ASME Boiler and Pressure Code*; acceptance standards for liquid penetrant and magnetic particle inspection are given in Articles 24 and 25, respectively, of Sect. V.[13]

Figure 4.12 illustrates pitting, scratches, and weld spatter, conditions too often observed in welded mounting frames, particularly those of the pocket type.

4.3.4 Filter Clamping and Sealing

HEPA filters and adsorber cells must be carefully sealed to the mounting frame to achieve the required low penetration rates and to provide for easy replacement. Except for the fluid-seal design described at the end of this section, sealants are not a satisfactory substitute for gaskets. Experience in clean rooms and contaminated exhaust and air cleanup applications has shown that flat, closed-cell neoprene gaskets, ASTM D1056 grade SCE-43,[14] give the most satisfactory seal for high-efficiency filters, adsorbers, and demisters. There is no advantage in using shaped (molded) gaskets; not only are they more expensive, but research has shown that they are prone to leak.[15,16] Gaskets that are too soft (i.e., less than grade SCE-43) take an excessive compression set that may permit leakage when there is relaxation of the clamping bolts. Gaskets that are too hard (i.e., harder than grade SCE-44) require such high clamping loads to effect proper sealing that the filter itself can be distorted or damaged.

As little as 20% gasket compression is needed to effect a reliable seal when the thickness of the gasket is uniform to within ±0.01 in. and when the seating surface of the mounting frame is plane to within ±0.01 in.[16] However, these tolerances are much too restrictive for economical construction, and experience has shown that compressing an SCE-43 gasket at least 80% is usually necessary to effect a reliable seal over long periods. Eighty percent compression requires a loading of approximately 20

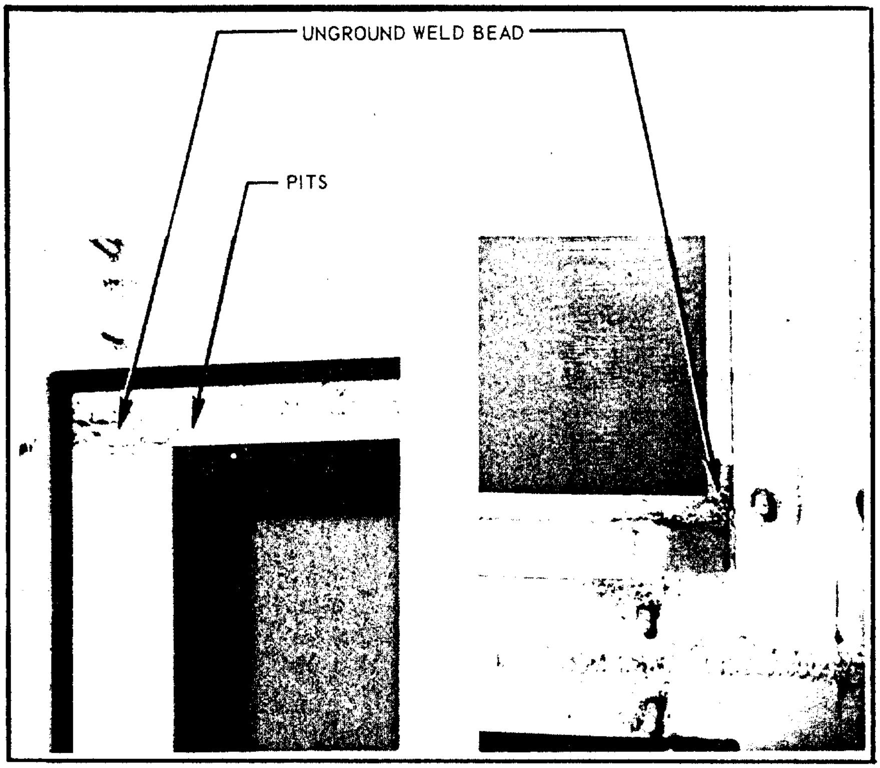

Fig. 4.12. Unacceptable filter-seating surface on HEPA filter mounting frame. Note pits, unground weld bead, and weld spatter, all of which contribute to leakage of contaminated air due to inability to properly seat the filter.

lb per square inch of gasket area, or a total clamping load of about 1400 lb for a 24- by 24-in. filter unit. The recommended procedure for installing filters is to initially torque the clamping bolts to produce 50% gasket compression and then to retorque them one or two weeks later to a total compression of about 80%.

Gaskets that are too thin may not give a reliable seal with the recommended frame tolerances given in Table 4.2, whereas those that are too thick may be unstable and tend to roll or pull off the flange of the filter case as they are compressed, perhaps to the extent that sections may be extruded between the case and mounting frame and produce a serious air leak. Recommended gasket sizes are $^1/_4$ in. thick by $^3/_4$ in. wide and $^1/_4$ in. thick by $^5/_8$ in. wide. Gaskets must be glued to the filter element rather than to the mounting frame, because they must be replaced with each filter change. Gaskets should have cut surfaces on both faces because the "natural skin" produced by molding sometimes tends to bridge discontinuities or defects in the seating surface, and because the silicone mold-release compounds used in the manufacture of sheet neoprene prevent proper adhesion of the gasket to the filter case.

Filter units and adsorber cells must be clamped to the mounting frame with enough pressure to enable the gasket to maintain a reliable seal when subjected to vibration, thermal expansion, frame flexure, shock, overpressure, and widely varying conditions of temperature and humidity that can be expected in service. Clamping devices must function easily and reliably after long exposure to hostile environments and, in addition, must be capable of easy operation by personnel dressed in bulky protective clothing, gloves, and respirators (or full-face gas masks) while working in close quarters. Experience has shown that a simple nut-and-bolt system gives satisfactory service under these conditions. Eccentric, cam-operated, over-center, or spring-loaded latches and other quick-opening latches, such as the window latch design shown in Fig. 4.13, are not recommended for clamping of high-integrity components such as HEPA filters and adsorber cells. If the designer insists on using such devices, means for adjusting the throw of the device must be provided to compensate for deviations in the depths of individual filter (adsorber) units. These devices too often fail, because they get out of adjustment, relax, or are damaged (during maintenance) during a period of service,

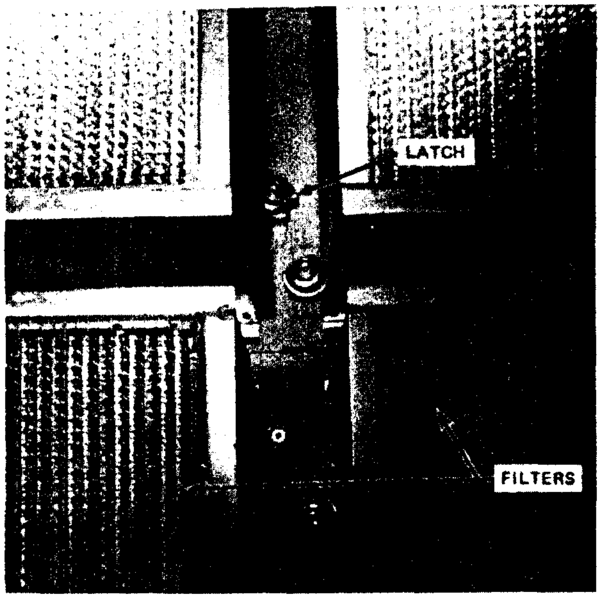

Fig. 4.13. Window latch latching devices for clamping filters. Latches bear on backs of the front flanges of the filters. This method is not reliable for installing HEPA filters.

which results in inadequate clamping pressure on the component or the need to replace the latch. In a radioactively contaminated filter system, replacement can be a hazard to personnel and to the filters and/or adsorbers installed in the system. Nut-and-bolt clamping, on the other hand, entails the removal and handling of a large number of nuts; this procedure can be a problem during a filter change in a highly radioactive system.

Major requirements for filter and adsorber clamping systems are magnitude and uniformity of clamping pressure. At least four, and preferably eight, pressure points are required for HEPA filters and demisters, as shown in Figs. 4.5 and 4.9. Individual clamping of each filter unit is preferred. Common bolting in which holding clips (or bolts) bear on two or more adjacent filters or adsorber cells, as shown in Fig. 4.14, has been widely used because it is less expensive than individual clamping and requires fewer loose items to be manipulated within the confines of the housing during a filter change. However, common bolting limits the ability to adjust or replace individual filters in the bank without upsetting the seals of adjacent units. In Fig. 4.14*a*, for example, replacement of one of the center filters might upset the seals of eight surrounding filters. In the improved system shown in Fig. 4.14*b*, no clip bears on more than two filter units, and the seals of only four surrounding filters are upset when replacing a filter unit. The clamping system shown in Fig. 4.14*b* has the advantage that clips and nuts do not have to be removed to replace filters, since the clips can be rotated out of the way after the nuts have been loosened. Although this type of clamping system has been used with good success in nuclear and non-nuclear applications, many in-place test personnel object to it because of the extensive leak chasing often required before a satisfactory in-place test can be achieved. Leak chasing occurs when, on adjusting or replacing one filter, the seals of surrounding filters are upset, which results in new leaks that have to be corrected; this process is time-consuming and costly and, when conducted in a contaminated housing, can result in lengthy exposure of personnel.

Because of their weight, eight pressure points are essential for clamping type I (pleated-bed) adsorber cells. For clamping type II (tray-type) cells, two pressure points on the top and two on the bottom edges of the front plate, with individual clamping as shown in Fig. 4.15, are needed for proper sealing. Clamping on the short sides only is not adequate. As Figs. 4.7 and 4.15 show, captive nuts reduce the number of loose items that must be manipulated within the confines of the filter housing during filter or adsorber replacement, but they must be provided with means for preventing rotation when positioned for withdrawal of the filter.

The minimum bolt size recommended for individually clamped filters is $^3/_8$-16-UNC, but $^1/_2$-11-UNC or $^5/_8$-11-UNC bolts are less prone to damage. For type I adsorbers, $^5/_8$-11-UNC bolts are necessary. Figure 4.16 shows several methods of installing bolts to the mounting frame in which the bolts are threaded rods. Although methods (*a*) and (*b*) in Fig. 4.16 avoid penetration of the mounting frame (and thereby avoid potential future leaks), they present problems in alignment and location. Method (*c*) overcomes these problems and also the problem of producing a weld bead at the base of the bolt (if too large, the weld bead would interfere with proper seating of the filter). Of the methods shown, (*b*) is probably the least expensive and (*a*) is the most expensive. Care must be taken with method (*c*) to avoid pushing the base of the bolt too far through the frame, since this increases the cost of welding appreciably and makes complete seal welding difficult.

The nuts and bolts of the clamping system must be made of dissimilar materials to prevent galling and seizing. Bolting materials and clips must be resistant to corrosion. Stainless steel (300 series) bolts with

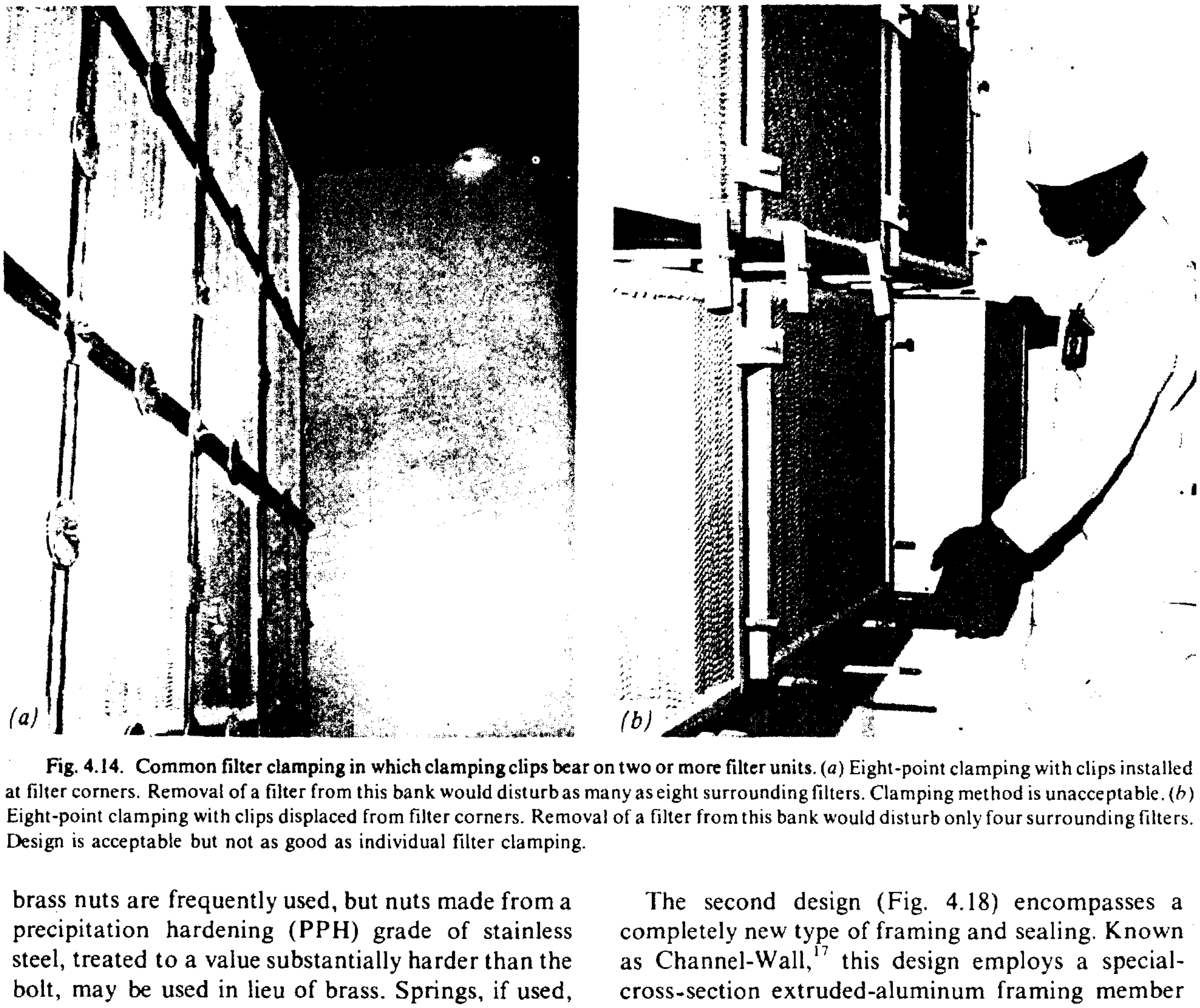

Fig. 4.14. Common filter clamping in which clamping clips bear on two or more filter units. (*a*) Eight-point clamping with clips installed at filter corners. Removal of a filter from this bank would disturb as many as eight surrounding filters. Clamping method is unacceptable. (*b*) Eight-point clamping with clips displaced from filter corners. Removal of a filter from this bank would disturb only four surrounding filters. Design is acceptable but not as good as individual filter clamping.

brass nuts are frequently used, but nuts made from a precipitation hardening (PPH) grade of stainless steel, treated to a value substantially harder than the bolt, may be used in lieu of brass. Springs, if used, should also be made from a PPH grade of stainless steel if they are to resist corrosion and relaxation over a period of service.

Two newly developed clamping and sealing methods that deserve mention, even though they cannot be given an unqualified recommendation because of limited field experience, are both proprietary. The first, developed by American Air Filter Company, employs long levers which rotate a pair of clips that bear on the back surface of the front flange of the filter, as shown in Fig. 4.17; two of these torsion-bar assemblies are required for each filter. A possible shortcoming of the design is that the clamps bear only on the top and bottom filter flanges, and there is no pressure on the sides of the case. The manufacturer reports that the system has been employed in a number of nuclear power plant air cleaning systems with excellent results.

The second design (Fig. 4.18) encompasses a completely new type of framing and sealing. Known as Channel-Wall,[17] this design employs a special-cross-section extruded-aluminum framing member (Fig. 4.18*b*) which presents a knife-edge sealing surface to the filter element. The filters have a channel filled with a nonflowing, nonvulcanizing silicone polymer around the sealing edge which fits into the knife edge of the mounting frame to form a positive seal between filter and frame. Rigidity of the mounting frame is not a consideration, since frame flexure cannot affect the seal or the filter. Clamping pressure need be sufficient only to hold the filter unit in place (if the filters are installed on the downstream side of the frame, clamping must be sufficient to resist displacement of the filter under normal operating filter resistance and the pressures produced by shock loadings in the system). Experience with this system has been primarily in clean room applications. Test results verify that the silicone fluid does not flow when tested under the conditions of the UL-586 hot-air test (which would, of course, destroy the filter-to-frame seal) and that the system can maintain sealing

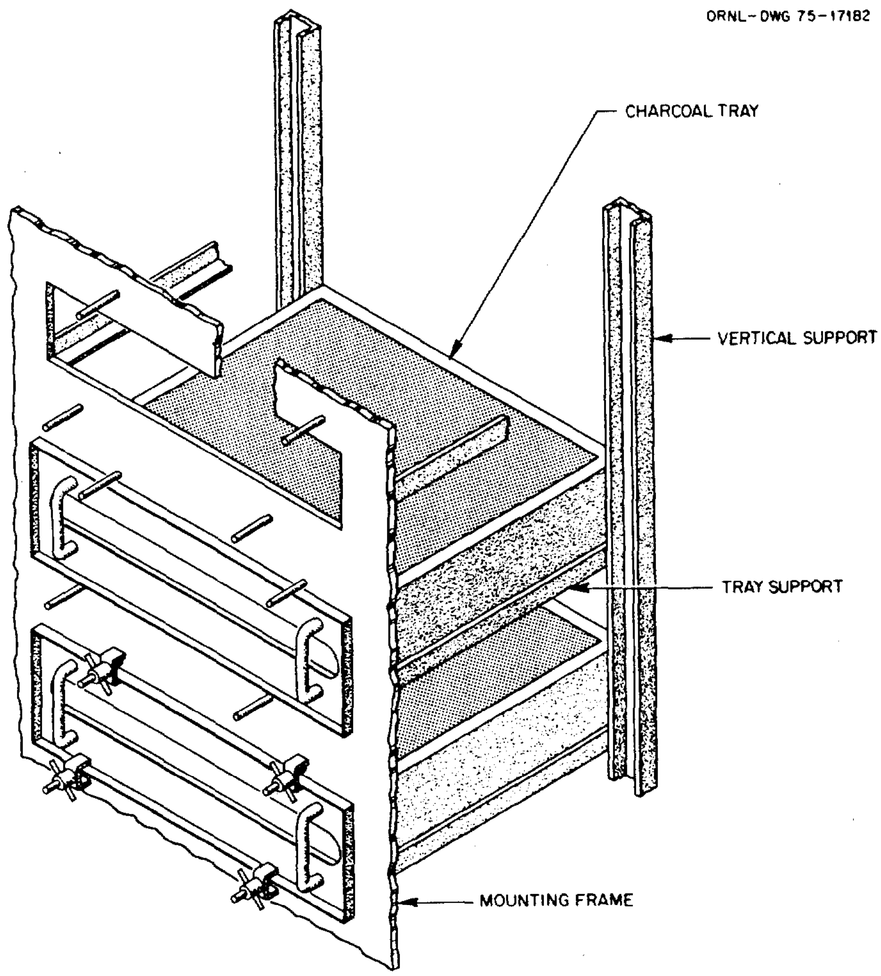

Fig. 4.15. Four-point individual clamping of type II adsorber cell. Note captive nuts to reduce number of loose parts to be handled during cell change.

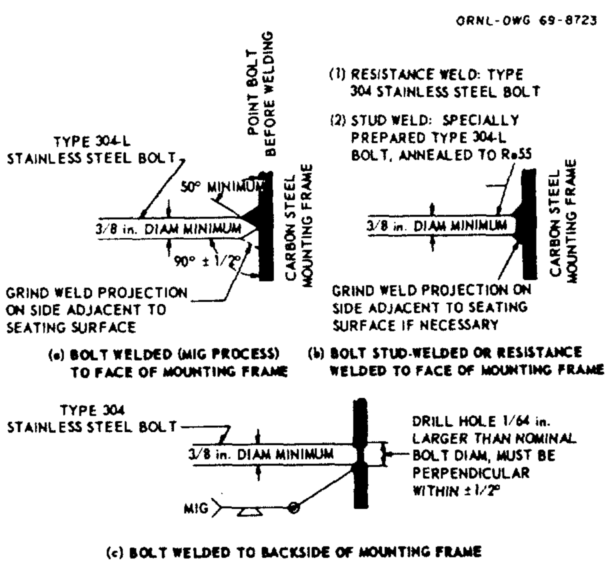

Fig. 4.16. Methods of welding clamping bolts to filter mounting frames.

integrity at filter-resistance values in excess of 10 in.wg. Although high levels of radiation (5 to 10×10^6 rads) tend to solidify the fluid, the seal is apparently not affected. It has been demonstrated that filter replacement requires substantially less time than that required for gasket-sealed systems.

4.3.5 Filter Support

A desirable feature from the standpoint of maintenance is a cradle or other support for the filter element as it is moved into position on the frame. The cradle should not obscure any more of the filter-to-frame interface than is necessary, to avoid interference with inspection as the filter is installed. Figure 4.5 shows an acceptable cradle design. The support shown in Fig. 4.19 is better because it obscures less of the gasket-frame interface. The cradle in Fig. 4.20 is unacceptable, because it obscures too much of the interface. In some installations, filters have been

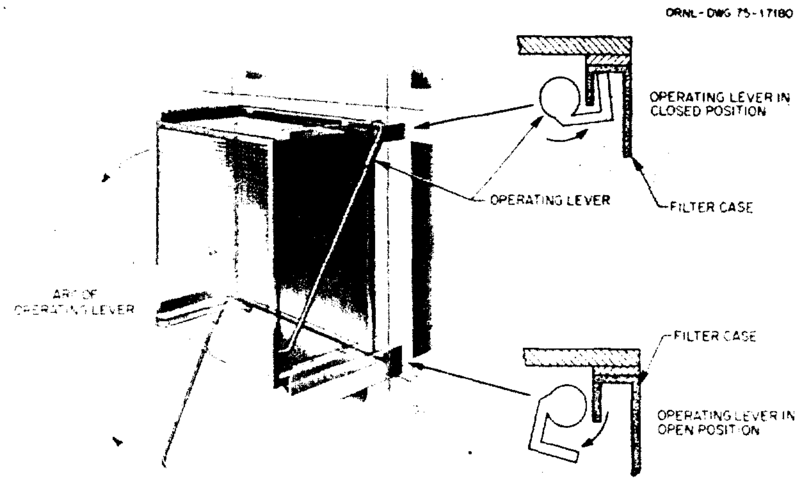

Fig. 4.17. Torsion bar clamping system. Details show end views of operating lever in closed and open positions. Note that clamping is on gasket flange of filter, and that clamping pressure is applied to only two sides of the filter. The operating levers are slightly bent when locked, which provides the spring pressure needed to compress the gasket. This method can be used only with steel-cased filters. It eliminates tools and loose items in the filter housing during a filter change and is easy and fast to operate. Courtesy American Air Filter Co.

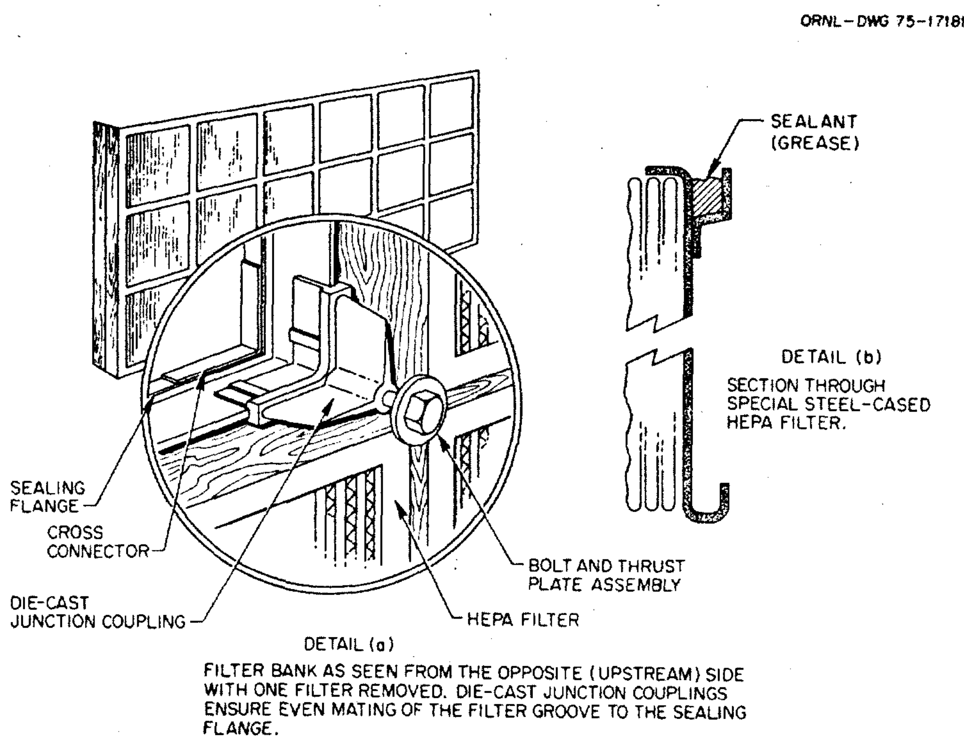

Fig. 4.18. Channel-Wall filter-sealing and mounting frame system. Design is proprietary and requires special filter units as shown in (*b*). Wood-cased filters have a $^3/_8$- by $^3/_4$-in.-deep groove routed in the sealing edge, in which the sealant is placed. (*b*) Section through special steel-cased HEPA filter. Courtesy Flanders Filter Corp.

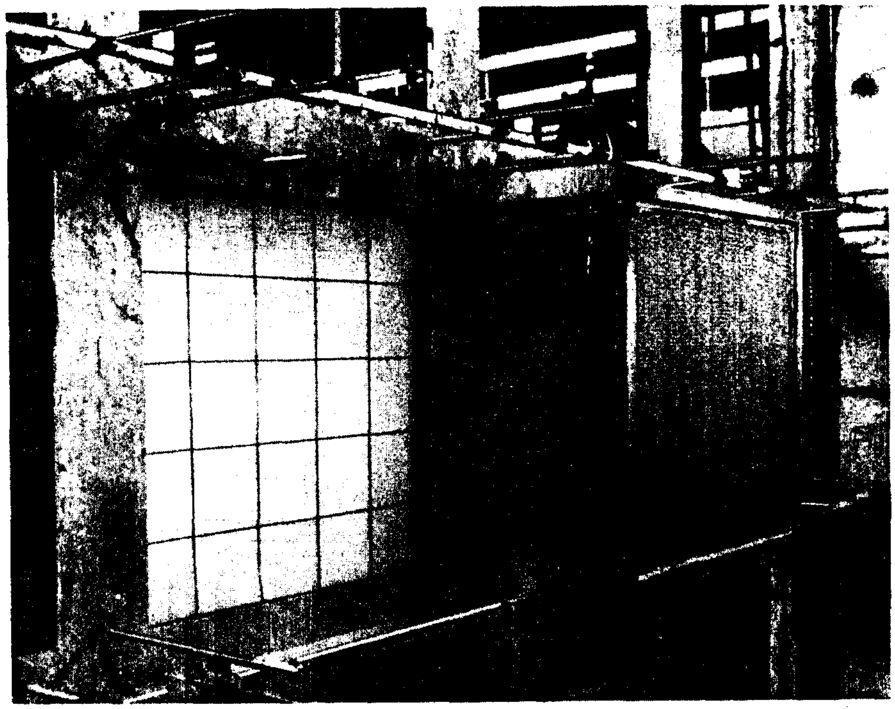

Fig. 4.19. Good filter-support-cradle design. Note all-around access to gasket-frame interface. Courtesy CTI-Nuclear, Inc.

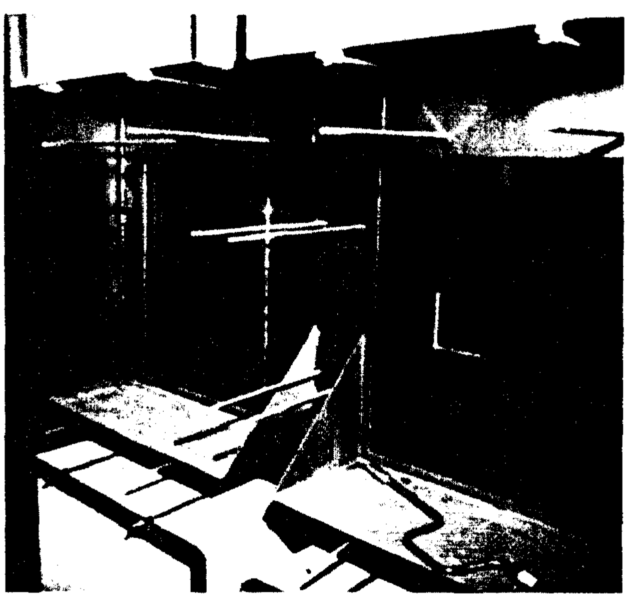

Fig. 4.20. Unacceptable filter-support cradle. Note that the cradle obscures much of the filter mounting frame interface.

supported on the bottom clamping bolts; this risks damage to the threads of the clamping bolts and is not recommended. Figure 4.21 shows a filter mounting frame in which a second frame structure, spaced a few inches ahead of the mounting frame, provides the function of a support cradle. Filter clamping bolts are attached to the front structures, which permits the use of short bolts and avoids penetration of or welding on the mounting frame itself.

4.4 SIZE AND ARRANGEMENT OF FILTER AND ADSORBER BANKS

The size (nominal airflow capacity) and orientation of filter banks (vertical or horizontal), the location of filters on the bank (upstream or downstream side), and the floor plan and height of the bank all affect the reliability, performance, maintainability, and testability of the air cleaning system. Savings gained by designing for minimum space and materials can be wiped out many times over by the higher operational, maintenance, and testing costs that will result from higher pressure drop and cramped working space in the filter housing.

4.4.1 Vertical Filter Banks

Vertical banks with horizontal airflow are preferred in contaminated exhaust systems, because the filters are more favorably oriented with respect to ease of handling, mechanical strength of the filters, and collection of condensate. In horizontal banks, filter pleats can collect moisture, which in time may

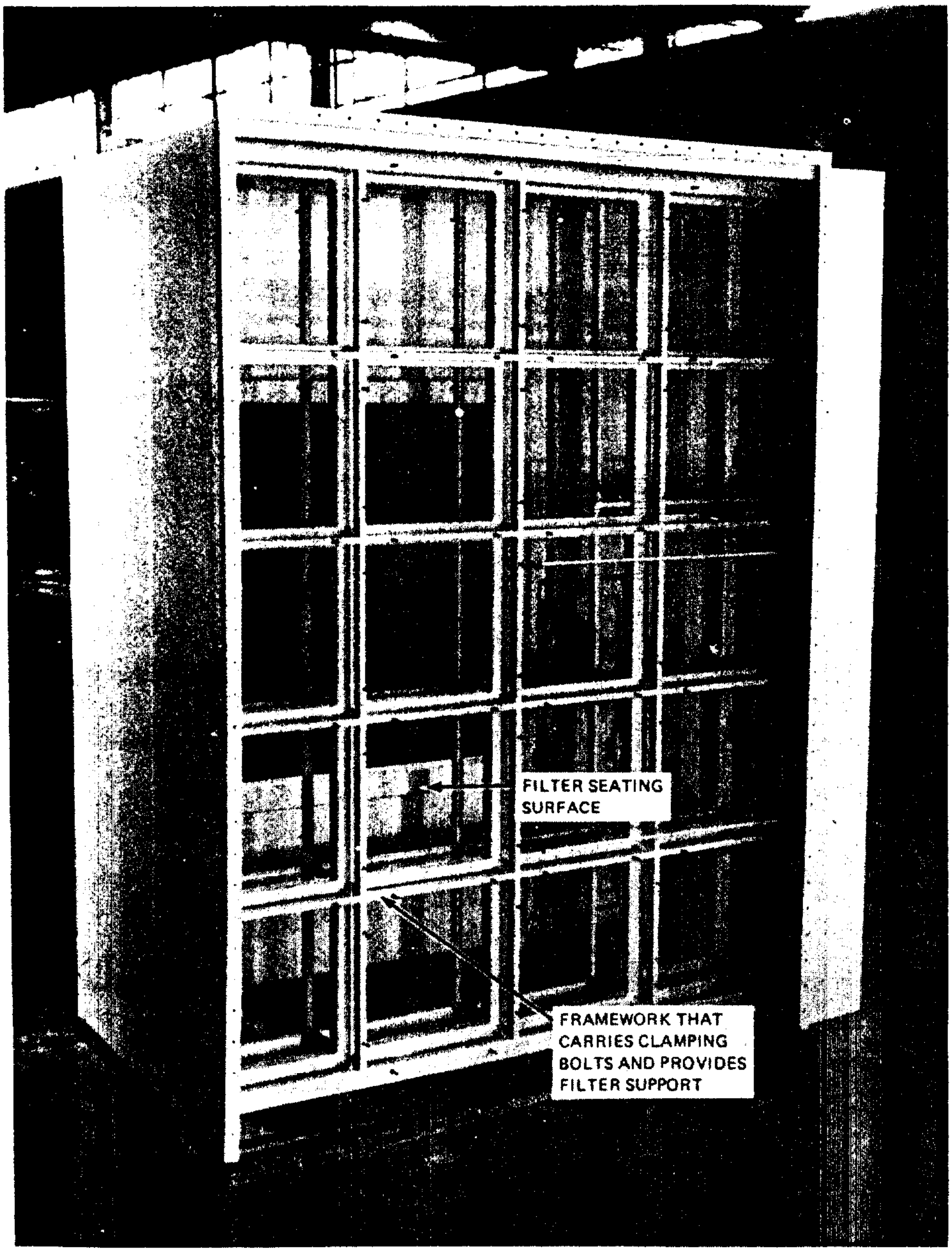

Fig. 4.21. Two-part, face-sealed HEPA-filter mounting frame. Filters seal to rear frame. Front frame provides filter support during maintenance and carries clamping bolts. This arrangement permits shorter clamping bolts (which decreases the possibility of misalignment of bolts during maintenance). The arrangement also prevents the bolts from being welded on or penetrating the primary frame to which the filters seal. The 4-wide by 5-high array is poor from the standpoint of maintainability; a service gallery at the third filter level would be desirable. Courtesy MSA Research Corp.

cause deterioration of the medium, separators, adhesives, and filter casings. In vertical banks, filters must be installed with vertical pleats and separators because horizontal pleats tend to sag over a period of time, as can be seen in Fig. 4.22. The pleats of type I adsorber cells and the beds of type II cells, on the other hand, must be installed horizontally to avoid settling of adsorbent in the cells.

4.4.2 Horizontal Filter Banks

If filter banks must be horizontal, upflow is preferred to downflow, because filter-core sagging is offset to some extent by air pressure and because there is less chance of cross-contamination from the dirty side to the clean side of the system. With downflow, contaminated dust dislodged during a filter change will fall into the clean side of the system. Also, liquid collected in filter pleats of a downflow system will eventually seep through the medium and carry dissolved contaminants into the clean side of the system. On the other hand, upflow systems may require withdrawal of contaminated filters into the clean zone. When horizontal installation must be used, filters should be mounted on the upper side of the mounting frame so that their weight will load rather than unload the gaskets. Replacement of filters from above is easier and less costly than replacement from below. The discussion of structural strength of filter mounting frames was based on vertical banks. The design of a horizontal mounting frame must also take into consideration the weight of the filters (Table 4.2) and the weight of the frame, in addition to air pressure loading. Otherwise, tie rods between the frame and the ceiling, or other means of supporting the frame, must be provided.

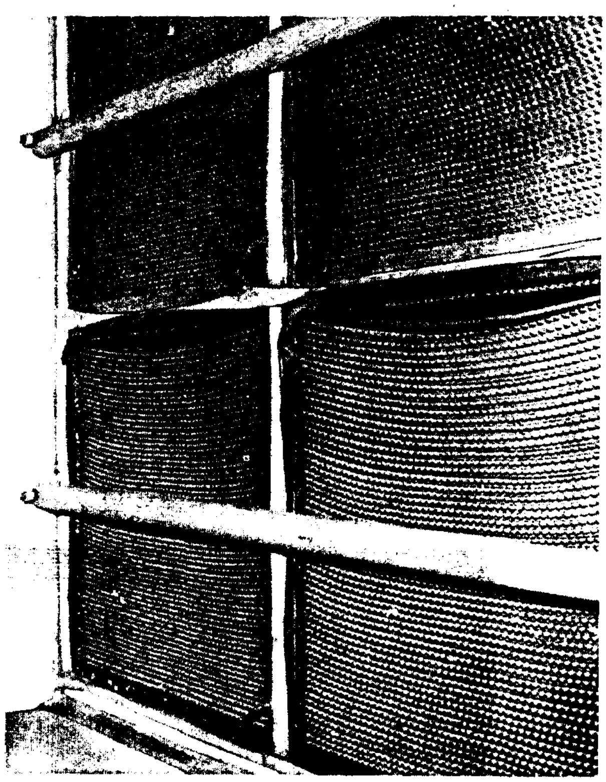

Fig. 4.22. Improperly installed HEPA filters. Horizontal pleats have sagged nearly 2 in. after six to eight months of service. Pleats should be vertical. Also note peeling duct tape used to seal between filters and between filters and housing, which have been simply stacked into the duct opening. These practices are unacceptable for any type of filter installation.

4.4.3 Location of Filters on Mounting Frame

No clear-cut preference can be justified for mounting filters on the upstream side or the downstream side of the mounting frame; both methods have been used successfully. ERDA usually recommends downstream mounting, whereas many ERDA contractors prefer upstream mounting. The following advantages are cited for upstream mounting of filters:

1. Filters are withdrawn into and handled within the contaminated side of the system during a filter change. No contaminated materials need be brought into the clean side of the system, so there is more complete separation of the clean and dirty sides of the system.
2. Airflow tends to load the filter gaskets during operation, so there is less likelihood of leaks.

Disadvantages of upstream mounting are (1) personnel have to work within a highly contaminated zone during a filter change; (2) there is the possibility that contamination can be tracked or carried out of the contaminated zone by workmen unless there is careful planning and execution of a filter change; and (3) filter clamping devices are located in the dirty side of the system where they are most exposed to corrosion and dirt.

The following advantages are cited for downstream mounting of filters:

1. Filters are withdrawn into and handled within the clean side of the system; therefore, there is less likelihood of tracking or carrying contamination into the building during a filter change.
2. Personnel are not required to work in a highly contaminated portion of the housing during a filter change.

3. Filter clamping devices are located on the clean side of the system and are therefore less subject to corrosion.

4. Leak probing of installed filters is more sensitive. If there are gasket or casing leaks, the driving force of air entering the filter forces the test aerosol through the leak, and it is readily detected. With upstream mounting, on the other hand, any test aerosol that goes through a leak in a gasket or filter case mixes with the air and test aerosol passing through the opening in the mounting frame, thus obscuring the leaks. Although the existence of a leak may be disclosed by a test, the location of the leak cannot be easily determined by probing.

5. Only the upstream face of the filter is contaminated during operation; the outer surfaces of the filter case and the downstream face of the filter pack are not usually contaminated.

The disadvantages of downstream mounting are (1) filter gaskets tend to be unloaded by air pressure during operation, thus increasing the likelihood of gasket blowby; and (2) the contaminated filters must be withdrawn into the clean side of the system in a filter change. The second disadvantage can be offset by "fixing" the contaminated dust by spraying the upstream side of the filter pack with paint or acrylic spray or by taping cardboard over the upstream face of the filter; however, this procedure would require personnel to enter the contaminated chamber of the housing, and the possibility still exists of dislodging contaminated dust into the clean side of the system, either from the filter itself or from the edges of the frame opening (which is exposed to contaminated air during operation).

Filters have been mounted on both sides of a mounting frame in some installations when two-stage filtration was specified. Although this dual mounting saves space and prevents carry-over of contamination to the clean side of the system when the upstream filter is replaced, it makes reliable in-place testing of filters impossible. When new filters are installed, the first set that is installed can be tested, and then the two sets together can be tested as a single bank. However, the first set will obscure the deficiencies of the second set during the second test. In addition, the set of filters installed first, and found satisfactory by test, could be damaged during installation of the second set, and the damage could escape discovery. Double mounting of filters has the additional disadvantage that fire in the upstream filter will readily jump to the second set, so that any advantage of double filtration during the fire would be lost. Therefore, double mounting is not recommended and is prohibited by ERDA where it has the authority to control design.

Similar problems exist when prefilters or adsorber cells are installed back-to-back with HEPA filters (Fig. 4.23), since probing for leaks between components is impossible and there is risk of damage to the fragile and critical HEPA filter. With back-to-back installation of HEPA filters, the reliability of the individual filters is unknown. A cardinal rule in contaminated exhaust systems is that no credit is granted for untested and untestable filters. Therefore, although two sets of filters may be provided by double mounting, the operator cannot take credit for two-stage filtration or series redundancy. A third

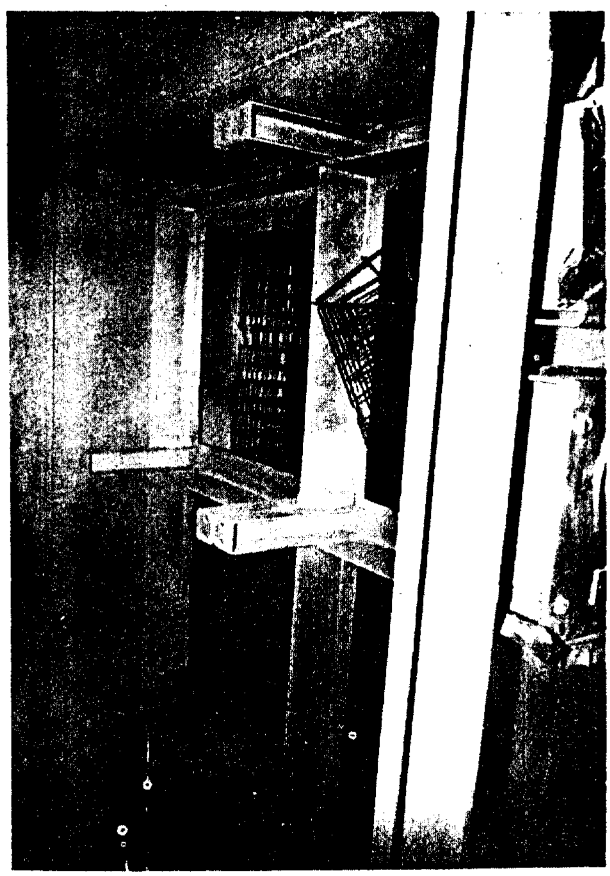

Fig. 4.23. Back-to-back installation of prefilters and HEPA filters prevents access to upstream face of HEPAs. Note potential for damage to HEPA filters when installing prefilters. Inspection of upstream face of HEPA filters is impossible unless prefilters are removed. Back-to-back installation of prefilters to HEPA filters, HEPA filters to HEPA filters, or HEPA filters to adsorbers is not recommended.

bank of filters in series with the double bank would be necessary by this rule, and, in fact, this type of wasteful multiplication of filter banks has occurred in some systems.

4.4.4 Size of Banks

A nominal limit of 30,000 cfm is recommended by ERDA and NRC for any single filter or adsorber bank. For larger systems, this limit requires that the system be segmented into two or more smaller subsystems, each contained in an individual housing and having an installed capacity of 30,000 cfm or less. The purpose of this requirement is to facilitate maintenance and in-place testing, to improve control in the event of a system upset, and to enhance reliability of the total system. A 30,000-cfm bank is about the largest that can be in-place tested conveniently (Chap. 8). In addition, by having the system broken into two or more air cleaning units, testing and filter replacement can be conducted in one unit while the other unit remains on-line. NRC Regulatory Guide 1.52 recommends such redundancy for ESF air cleaning systems in reactors.[18] The designer may also choose to segment a system into units of substantially less than 30,000 cfm when redundancy is desired to achieve advantages of control, maintainability, and testability.

4.4.5 Arrangement of Banks

Spatial arrangement of filters on a mounting frame influences operating performance and maintenance. If one were to specify twelve 1000-cfm filters ($24 \times 24 \times 11\frac{1}{2}$ in.) arranged in a 6-wide by 2-high array, it would create a difficult installation and maintenance situation, because personnel would be forced to crawl or work stooped over in the filter house. On the other hand, arranging the same bank in a 2-wide by 6-high array would make it impossible for one to reach the upper filters without bringing ladders or temporary scaffolding into the housing (a major source of filter damage) or providing a permanently installed work gallery. If the filters were arranged 3 wide by 4 high, there would still be the problem of access to the top tier of filters. The best solution is to arrange the filters in a 4-wide by 3-high array. For similar reasons, the best arrangement for a 6000-cfm system would be a 2-wide by 3-high array.

Insofar as possible, banks should be laid out in an array of three filters high or nine type II adsorber cells high. Where floor space is at a premium, the bank may be arranged with one 3-high array above another, with a service gallery between, as shown in Fig. 4.11. Thus an 18,000-cfm bank might be arranged in an array 6 wide by 3 high or 3 wide by 6 high, with a service gallery between the third and fourth tiers. The arrangement of a 24,000-cfm bank in a 6-wide by 4-high array would be undesirable. A better arrangement is an array 8 wide by 3 high, or, if the floor space is at a premium, two 4-wide by 3-high arrays, one above the other, separated by a service gallery. In no case should filter changing require the use of ladders or temporary scaffolding. To require a workman dressed in bulky protective clothing (with sight obscured by a respirator or gas mask and sense of feel dulled by double gloves) to manipulate a ladder or scaffold within the confines of a filter house is an open invitation to filter damage and personnel injury. Based on the 95th-percentile man,[19] the maximum height at which a man can operate hand tools effectively is 78 in., and the maximum load he can handle at a height of 5 ft or more is 40 lb.[20] Therefore, provision for access to the higher tiers of filters is necessary. At costs of $80 to $120 per filter unit, any savings realized in first costs by not providing a permanent service gallery could be offset in only one or two filter changes by the cost of damaged filters alone. Service galleries in high banks reduce the costs of preparing for and cleaning up after a filter change. The pay-out period for a gallery in a 7-wide by 6-high filter bank was estimated to be about two years, based on labor savings only and taking no credit for prevention of potential filter damage.[21]

Filter banks should be rectangular. The use of odd-shaped banks, such as the one shown on the left in Fig. 4.24, in order to limit installed filter capacity to calculated system airflow requirements, increases construction costs significantly. By filling out the rectangle, as shown at the right of Fig. 4.24, construction costs will be less. In addition, if all nine spaces are filled with filters, operating costs may also be reduced, because the additional filter would permit operation at a lower flow rate per unit, with attendant longer filter life and reduced filter-change frequency, as discussed in Chap. 2. For the purposes of laying out adsorber banks, three type II (tray) adsorbers will fit vertically into the space occupied by one 24- by 24-in. HEPA filter.

4.4.6 Floor Plan of Filter Banks

Vertical banks may be arranged in a plane or in a U-shaped or stepped pattern to permit more filter units to be installed in a given housing width. Although there is no appreciable saving in floor space with U-shaped or stepped banks (Fig. 4.25), such arrangements may lend themselves to more favorable layout of nearby equipment. The use of a U-shaped or stepped bank in large systems may also have the advantage of improving inlet conditions to the fan or reducing the size and cost of duct transitions to the housing. Judicious layout of a bank can often reduce pressure losses in the system and bring about more uniform dust loading of filters, thereby equalizing the utilization of filters installed in the bank. If the open side of a U-arrangement is centered on the fan inlet, for example, the distances from the filters to the fan are more or less equalized, and the bank may, in effect, form an inlet box which enhances fan-inlet conditions and produces more uniform pressure drop across, and loading of, the filters. On the other hand, straight (plane) banks are safer from the standpoint

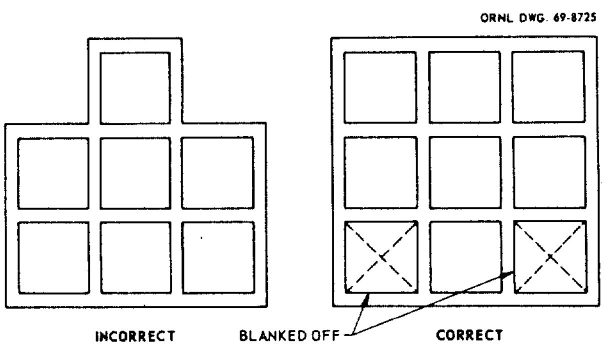

Fig. 4.24. Filter bank layout. Layout at left is much more expensive. If necessary to match installed filter capacity to calculated airflow requirements, fill out the rectangle and blank off some of the openings, as shown at right.

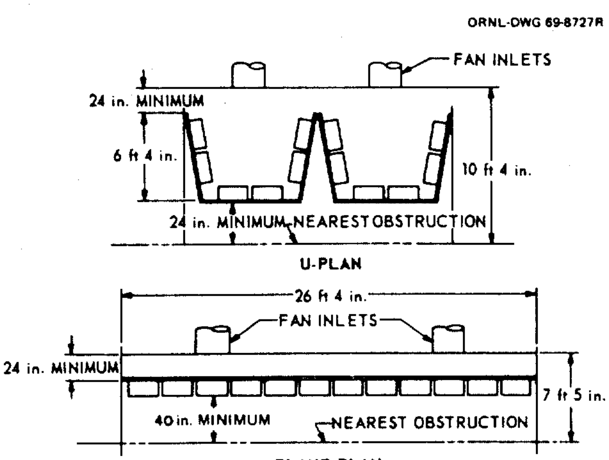

Fig. 4.25. Filter bank floor plans showing minimum clearances and floor space required.

of fire-spread than U-shaped or stepped arrangements.[22]

The procedures that will be required for construction and operational maintenance must be considered in planning. Adequate clearances for access must be maintained at turning points and between the bank and the nearest obstruction. Passageways between banks and between banks and the housing wall must be wide enough for welders to operate effectively and for workmen, dressed in bulky clothing, to get in to change filters; both welders and workmen will have to kneel or stoop to get to the bottom tier. A 95th-percentile man, in a kneeling position, requires a minimum clearance of 36 in. from the face of the filters to the nearest obstruction, not including withdrawal space for the filter unit itself. A minimum clearance of 40 in. is therefore recommended between the face of one bank and the nearest obstruction. The principal dimensions for U-shaped arrangements are shown in Fig. 4.26. A maximum angle of 2 in 12 is recommended. Stepped banks are usually laid out at right angles.

4.5 HOUSINGS

4.5.1 General

Large man-entry housings may be steel, concrete, or masonry; and they may be shop-built or field-fabricated. The trend, particularly in ESF systems, is increasingly toward shop-built steel housings. Carbon steel is the most common material of construction; however, stainless steel may be used when there is a potential for corrosion. Aluminum is not suitable in most cases because of the difficulty in obtaining reliable welds and the severe surface pitting that often occurs under service conditions. Aluminum is never used in reactor containments that employ caustic sprays. Galvanized steel may be used, but particular care must be paid to thorough removal of the coating prior to welding and to thorough cleaning and recoating of the weld area after welds are completed. Galvanized steel is not likely to give adequate corrosion protection in many continuously on-line filter systems. When ionizing radiation is present, concrete or steel-lined concrete housings or filter pits are necessary.

4.5.2 Arrangement and Location

Maintainability is a major consideration when laying out large filter housings. Although some systems may have only a single bank of HEPA filters,

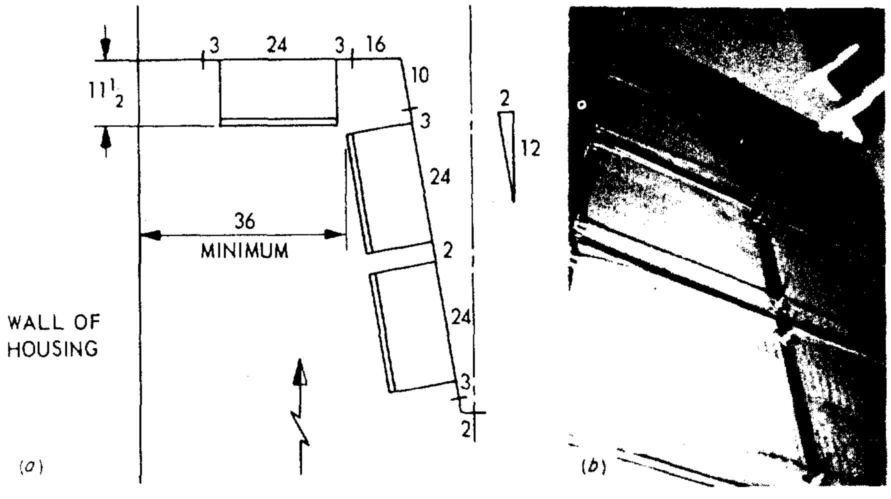

Fig. 4.26. Layout of U- and V-banks. (*a*) Recommended dimensions for laying out a U-shaped or V-shaped filter bank. (*b*) Poorly laid out V-bank. Note inadequate working space at apex of bank, 5-high filter layout with no service gallery, and minimal spacing of filters on the mounting frame.

most will have at least an additional bank of prefilters, and many will have multiple banks of HEPA filters. Those systems in which radioiodine releases must be controlled will also require one or more banks of adsorbers. Often a bank of demisters is required, with the result that there could be as many as six or more banks of components in a single housing. There must be sufficient clear corridor space adjacent to the housing for handling filters during a filter change and also adequate corridors to and from the housing. Dollies are often used to transport filters to and from the housing area. This practice makes for safer operations from the standpoint of both injury to personnel and contamination spread from dropped filters. When dollies are used, space must be allowed to get the dollies in and out and for loading and unloading. Additional space is desirable for stacking new filters (in their cartons) adjacent to the work area. Recommended clearances for housings and adjacent aisles or air locks are given in Fig. 4.27.

A factor sometimes overlooked is proper access to the filter housing. Too frequently, housings have been situated among machinery and equipment where workmen are required to climb between, over, or under obstructions to get to the door of the housing and then have inadequate work space. In some installations it has been necessary to carry filters, one at a time, over a roof and then rely on rope slings to transfer them from or to a waiting truck. It is essential to preplan the route for getting filters and adsorbers to and from the housing and to provide elevators or cranes when they have to be hoisted to an upper level.

High-risk operations often require segmented systems having two or more housings ducted in parallel that exhaust from the same area and vent to the same stack. Each housing must have inlet and outlet isolation dampers to permit one to be held in standby or, when both are normally operated simultaneously, to allow one housing to be shut down for maintenance or during an emergency. When high-activity alpha emitters such as plutonium or transuranic elements are handled, it may also be desirable to compartment the system in series, with separate housings for prefilters and HEPA filters, as well as in parallel for extra safety (Fig. 2.12).

Another important consideration in housing layout is the uniformity of airflow through the installed components. This is especially important for adsorbers, since flow through those components must be no greater than 120% of the specified rate (333 cfm per cell for type II adsorbers) to achieve the gas residence time required for efficient adsorption of radioactive organic iodine compounds. Figure 4.28 shows a good housing transition in a standby gas treatment system for a nuclear reactor; such long transitions are difficult, particularly in large housings. Nevertheless, every effort should be made to locate and design inlets and outlets to avoid

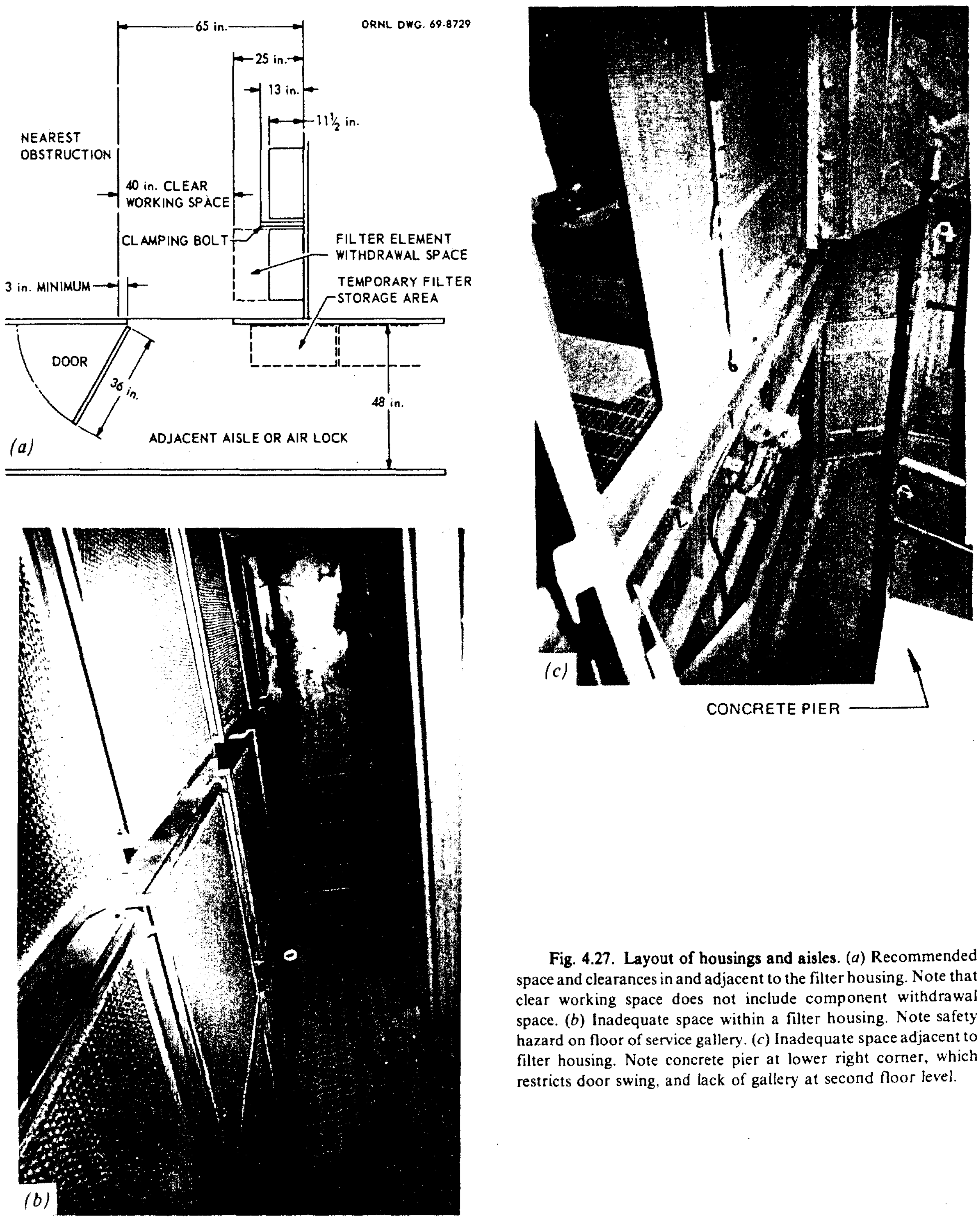

Fig. 4.27. Layout of housings and aisles. (*a*) Recommended space and clearances in and adjacent to the filter housing. Note that clear working space does not include component withdrawal space. (*b*) Inadequate space within a filter housing. Note safety hazard on floor of service gallery. (*c*) Inadequate space adjacent to filter housing. Note concrete pier at lower right corner, which restricts door swing, and lack of gallery at second floor level.

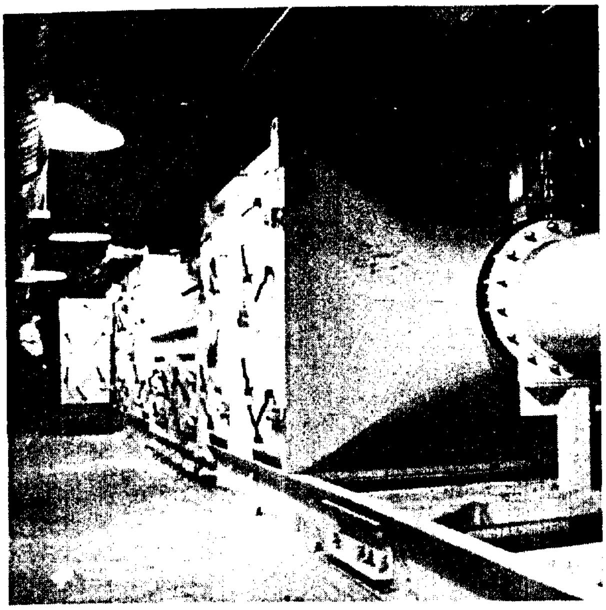

Fig. 4.28. Shop-built filter housing for nuclear reactor standby gas treatment system. Note long transition from duct to housing, which promotes uniformity of airflow through installed components. Courtesy CVI Corp.

stratification and to enhance the uniformity of airflow through components.

4.5.3 Steel Housings

Design practices used for conventional air conditioning and ventilation system ductwork and equipment casings are not adequate for high-reliability, high-efficiency contaminated-exhaust and air cleanup systems. Experience has shown that, under system upset and shutdown conditions, housing leaks can result in the escape of contamination to clean areas. Even with fans operating, reverse leakage of particles from the low-pressure side of a system (i.e., the interior of the housing or duct) to the high-pressure side (i.e., occupied area of the building) can sometimes occur because of dynamic and aspiration effects. Outleakage may also occur when the system is shut down. Filter housings for contaminated exhaust service must be able to withstand negative pressures, without damage or permanent deformation, at least up to fan cutoff, which may be ⩾20 in.wg in many systems. A pressure differential of 2 in.wg between the inside and outside of a housing produces a load of more than 1000 lb over every 10 ft^2 of the housing wall. If the filters are operated to economical pressure drops, the housing may have to withstand ten or more times this load without appreciable deflection. Pulsation and vibration may aggravate the condition. In addition, the housing should be able to withstand design shock loads without damage.

The references cited in Sect. 4.3 for the design, fabrication, and welding of mounting frames are also applicable to steel housings. Housings should be of all-welded construction, with bolted flange or welded inlet and outlet connections to the ducts and fans. Table 4.3 gives minimum sheet-metal thicknesses for sheet steel housings, and Table 4.4 gives minimum moments of inertia for steel reinforcing members. Sheet-metal thicknesses in Table 4.3 are based on a maximum deflection of $^1/_4$ in./lin ft at a pressure differential between the interior of the housing and atmosphere equivalent to 1.5 times the maximum pressure at fan cutoff. The moments of inertia for reinforcing members listed in Table 4.4 were selected so as not to exceed the allowable stress of the steel. Members up to 20 in. long were considered to be uniformly loaded beams with fixed ends, whereas members longer than 20 in. were considered to be uniformly loaded beams with simply supported ends. Sheet-metal thicknesses in Table 4.3 are given in U.S. gage numbers for sheet and fractional inches for plate.

Table 4.3. Minimum sheet-metal thicknesses[a] for welded steel[b] filter housings under negative pressure[c]

Dimensions of largest unsupported panel (in.)		Thickness (U.S. gage for sheet, fractional inches for plate) for negative pressure (relative to outside) of –					
Long side[d]	Short side	4 in. wg	8 in.wg	12 in.wg	20 in.wg	1 psi	2 psi
54 (2)	12	18	18	14	16	14	11
	24	18	14	11	12	8	$^1/_4$
	36	16	12	8	11	$^1/_4$	$^3/_8$
	48	14	12	6	8	$^1/_4$	$^3/_8$
80 (3)	12	18	16	14	16	14	11
	24	18	14	11	12	8	$^1/_4$
	36	16	12	6	11	$^1/_4$	$^3/_8$
	48	14	12	6	8	$^1/_4$	$^3/_8$
106 (4)	12	18	16	16	14	14	11
	24	18	14	12	11	8	$^1/_4$
	36	16	12	8	6	$^1/_4$	$^3/_8$
	48	16	10	6	$^1/_4$	$^3/_8$	

[a]Based on flat plate, edges held but not fixed (F. J. Roark, *Formulas for Stress and Strain*, 4th ed., McGraw-Hill, New York, 1965), and maximum deflection of 0.25 in. ft between reinforcements.

[b]30,000 to 38,000 psi yield strength.

[c]Metal thicknesses less than No. 18 U.S. gage are not recommended because of welding problems.

[d]Length based on 2-in. spacing between 24- by 24-in. filter units; the numbers within parentheses denote number of filter units. The metal thicknesses are adequate for panel lengths within ±10 in. of the length shown.

Table 4.4. Recommended minimum moments of inertia for selecting reinforcing members for steel filter housings under negative pressure[a,b]

Reinforcement		Moment of inertia (in.^{4})[d] for negative pressure (relative to outside) of –					
Length[c] (in.)	Spacing (in.)	4 in.wg	8 in.wg	12 in.wg	20 in.wg	1 psi	2 psi
54 (2)	12	0.04	0.04	0.04	0.04	0.04	0.08
	24	0.04	0.04	0.04	0.06	0.08	0.16
	36	0.04	0.04	0.05	0.09	0.12	0.24
	48	0.04	0.05	0.07	0.12	0.16	0.32
80 (3)	12	0.04	0.04	0.05	0.08	0.11	0.21
	24	0.04	0.06	0.09	0.16	0.21	0.43
	36	0.05	0.10	0.14	0.24	0.32	0.63
	48	0.06	0.13	0.19	0.32	0.42	0.86
106 (4)	12	0.04	0.09	0.13	0.22	0.30	0.60
	24	0.09	0.18	0.26	0.44	0.60	1.19
	36	0.13	0.27	0.39	0.66	0.90	1.79
	48	0.18	0.36	0.52	0.88	1.19	2.38
132 (5)	12	0.09	0.17	0.26	0.51	0.69	1.39
	24	0.18	0.34	0.52	1.02	1.39	2.78
	36	0.27	0.51	0.78	1.53	2.08	4.17
	48	0.36	0.68	1.04	2.04	2.76	5.55
158 (6)	12	0.15	0.29	0.44	0.73	1.0	2.0
	24	0.29	0.59	0.88	1.46	2.0	4.0
	36	0.44	0.87	1.32	2.19	3.0	6.0
	48	0.58	1.16	1.76	2.19	4.0	8.0

[a]Based on permissible deflection of $^1/_8$ in./ft.

[b]Uniformly loaded beam, 50% simply supported and 50% fixed ends assumed.

[c]Length based on 2-in. spacing between 24- by 24-in. filter units; the numbers within parentheses denote number of filter units. The data given are adequate for any length within ±10 in. of length given.

[d]Structural angles can be chosen from the tables given in the AISC *Manual of Steel Construction*.

Housings installed inside a reactor containment may experience a pressure lag during rapid pressurization of the containment following a major accident. Unless the housings are equipped with pressure-relief dampers, this lag could result in a substantial enough pressure differential between the housing and containment to collapse the housing.

Reinforcing members should be spaced to minimize vibration and audible drumming of the housing walls which can be transmitted through the system. Reinforcements should be installed on the outside of the housing, when possible, to eliminate interior ledges and projections that collect dust and constitute hazards to personnel working in the housing. All sharp corners, welds, weld spatter, and projections inside the housing should be ground smooth. The housing design must minimize cracks and crevices that are difficult to clean and that may collect moisture that can cause corrosion.

Mastics and caulking compounds, including silicone-base, RTV sealants, deteriorate in service and should not be used for sealing between panels and sections of a contaminated exhaust housing. Lock seams, rivets, and bolts used in conventional construction for joining panels do not produce leaktight joints. Leaks upstream of the filters are not permissible because of possible outleakage of contamination, and inleakage of air downstream of the filters results in reduced system performance. When bolted flange joints are used between the housing and ducts, $1^1/_2 \times 1^1/_2 \times {}^1/_4$-in.-angle flanges with ASTM D1056 grade SCE-45 or 30–40 Shore-A durometer neoprene gaskets are minimums.[14] Maximum bolt spacing of 4 in. is recommended for flanges.

Shop fabrication of housings is recommended over field fabrication because of the superior workmanship and control possible under shop conditions. Figure 4.29, which shows two redundant

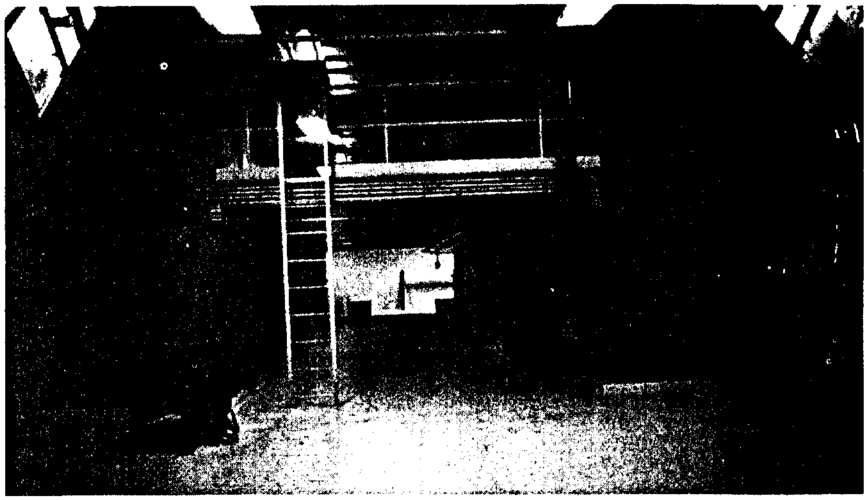

Fig. 4.29. Redundant units of nuclear reactor auxiliary-building ventilation system. Sections of the housings were shop-fabricated and assembled in the field. Each housing has 32,000 cfm capacity in a 4-wide by 8-high filter array. Note service gallery between housings and installation in a room that can be isolated as a contamination zone.

32,000-cfm units of an auxiliary building ventilation system for a nuclear reactor, illustrates that shop fabrication is practical, even for very large housings. Note the service gallery between units, which continues on into the housings. These housings were built in sections and assembled in the field. Field joints for such housings should be seal-welded, since mastic and gasket-sealed joints cannot be considered reliable for permanent installations.

4.5.4 Masonry and Concrete Housings

Filter housings for low-gamma-activity systems and vaults for high- (or potentially high-) gamma-activity systems are sometimes built as an integral part of the building structure. Concrete block construction that meets requirements for at least a 2-hr fire rating[23] is suitable for low-activity systems, but cinder block and other low-density material should not be used. Suitable block and ceiling constructions for low-activity system housings are shown in the UL *Building Materials List*.[24] Columns and bearing walls beneath masonry housings must have at least a 3-hr fire rating, and a 4-hr rating is preferred. Interior walls and ceilings should be plastered with $^1/_2$ in. of gypsum plaster and coated with epoxy or other impermeable paint to seal the surfaces and facilitate cleaning and decontamination. Blocks must be sealed to the floors along the entire perimeter. After sealing is completed, housing and mounting-frame leak tests should be made as described in Chap. 8. Areas particularly susceptible to leakage are door frames and flush-mounted items, such as light switches, on interior or exterior surfaces. This type of construction is suitable for secondary containment rooms in which large housings or multiple single-filter systems are installed (see Figs. 4.2 and 4.29).

In high-radiation-level or potentially high-radiation-level systems (e.g., a reactor or fuel reprocessing plant), filters may have to be installed in poured concrete housings or underground concrete pits. Figure 2.13 shows a typical installation of this type. When unusually leaktight construction is required, as for a filter system connected directly to the containment vessel of a nuclear reactor, a complete steel lining may be required inside the pit. Concrete housings and pits must be designed in accordance with recognized radiation shielding principles,[25] in addition to standards of the American Concrete Institute (ACI) and the Concrete Reinforcing Steel Institute (CRSI). Barite, magnetite, or other high-density concrete is recommended for shielding blocks and portions of the housing or pit that extend aboveground. ANSI N101.6 provides guidance to the construction of concrete radiation shields.[26]

Particular care must be taken with concrete construction to avoid spalling and cracking that could result in the leakage of unfiltered air and rough surfaces that are difficult to decontaminate. Surfaces that are exposed to radioactive substances must have a smooth finish that is resistant to wetting and free of defects that can trap contaminants. An example of undesirable cracking, spalling, and surface roughness, such as that frequently found in concrete construction, is shown in Fig. 4.30. Cracks such as those shown can be repaired by heavy undercutting and grouting with epoxy; however, this process is time-consuming, costly, and subject to the deficiencies of poor workmanship. Cracks can be minimized by the use of high-strength concrete (3000 lb at 28 days) and the liberal use of reinforcing steel. High-strength concrete also minimizes spalling problems. Curbs and steel embedments should be provided for the installation of filters, as discussed in the following section, and interior corners should be rounded or coved with a 2-in. minimum radius to facilitate painting and decontamination.

4.5.5 Seal Between Mounting Frame and Housing

A critical point in housing construction is the seal between the mounting frame and housing. A seal weld should be employed, except for remotely maintained systems in which a gasketed seal between a removable mounting frame and the housing is used to enable removal of the entire assembly of mounting frame and filters following an accident (see Fig. 9.12). Figure 4.31 shows the usual method of welding the mounting frame into a steel housing. The perimeter angle is welded to the housing on both sides all around. The frame-to-housing seal weld sometimes fatigues and cracks under service conditions, particularly when the housing is subjected to excessive vibration, shock loading, and frequently when materials of construction of frame or housing are too light. Two alternate frame-installation methods that minimize the possibility of bypassing the filters in the event of seal-weld cracks are shown in Fig. 4.32. Any of the methods shown are acceptable.

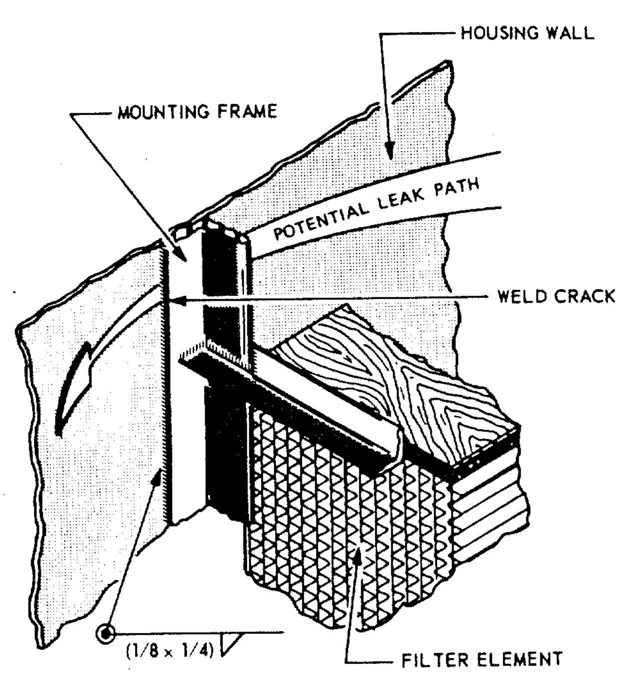

Fig. 4.31. Acceptable method for seal-welding mounting frame to housing. Weld crack and leak path show how a fatigued weld could result in bypassing the filters.

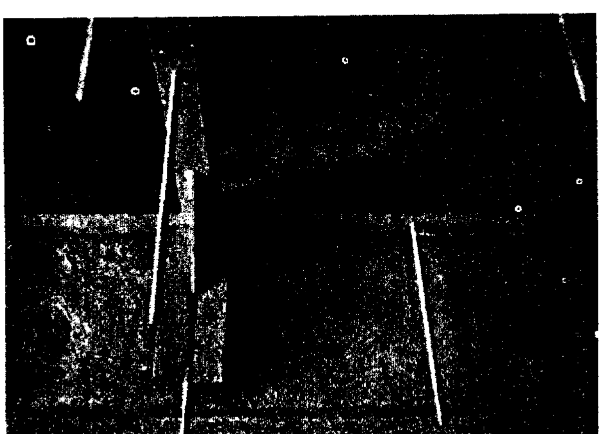

Fig. 4.30. An unacceptable concrete surface. Note cracks, spalls, and surface roughness that could result in leakage under the filter frame, trap contaminated material, and interfere with decontamination.

When a housing is installed on a concrete floor, the seal between mounting frame and floor is made by welding to a structural member embedded in the floor, as Fig. 4.33 shows. An angle (as shown) or a channel or I-beam with web vertical may be used to provide a labyrinth seal between the embedded member and concrete. Channels and I-beams should not be embedded with flanges pointing down, since this would trap air and cause voids in the concrete, thus providing a possible leakage path. Anchors (shown in Fig. 4.33) are desirable with angles or channels to oppose overturning forces on the mounting frame due to air pressure. For masonry and concrete housings and pits, embedments in walls and ceilings (shown in Fig. 4.34) are also required. Wall, ceiling, and floor embedments are welded together at the corners to form a continuously sealed surround for the mounting frame.

4.5.6 Housing Floor

Steel housings should, if possible, have steel floors welded continuously to the walls of the housing. In no case should the housing be installed on a wood floor

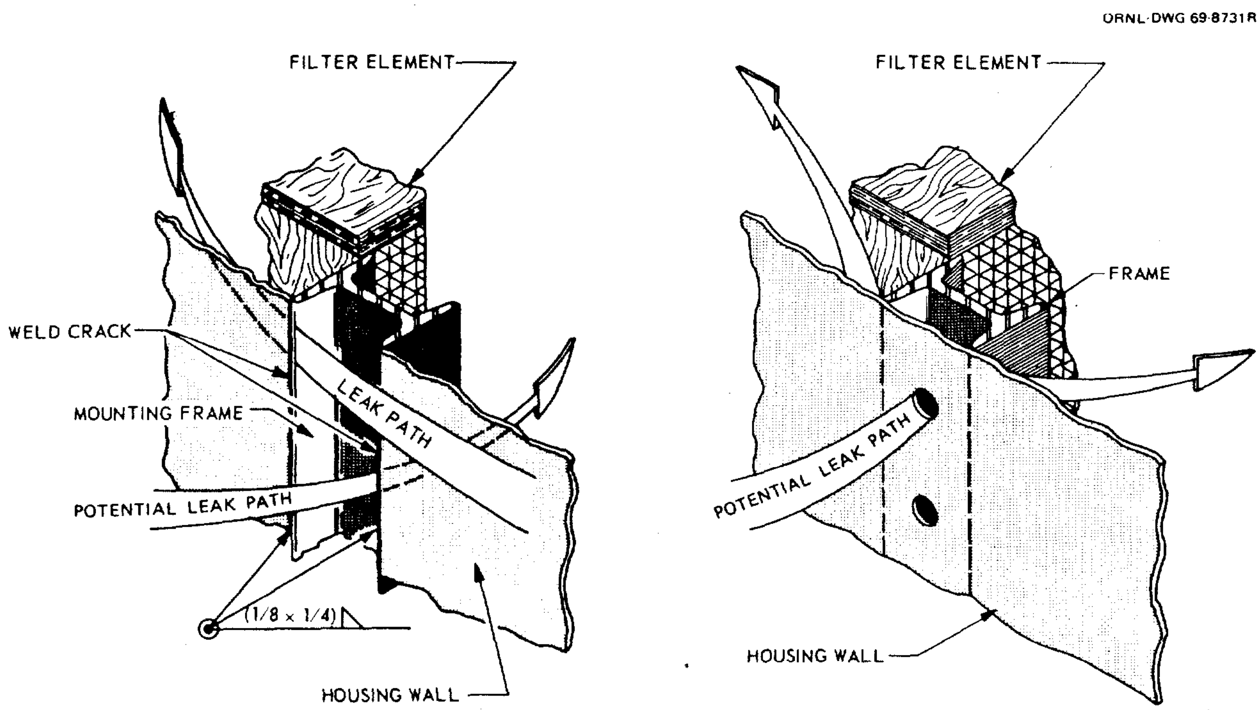

Fig. 4.32. Methods of welding frame to housing to ensure that weld cracks result in inleakage instead of outleakage. In both installation methods, both legs of the I-beam are seal-welded to the housing. Because pressure inside the housing, both upstream and downstream of the filters, is below atmospheric pressure, a crack in either seal weld will result in inleakage to, rather than outleakage from, the housing.

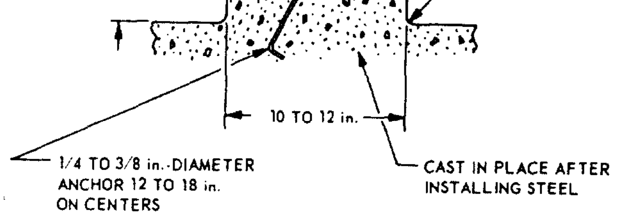

Fig. 4.33. Embedded structural member for seal-welding filter mounting frame to a concrete floor. Note anchor bolts, curbs, and seal weld from air-entering side.

or on a floor having less than a 3-hr fire rating. A channel or I-beam curb, welded to the floor, is recommended to raise the filter mounting frame off the floor. When steel housings are installed on concrete floors, curbs should be provided under the mounting frame (Fig. 4.33) and walls. An embedded member must be provided in the curb under the mounting frame.

Floors of filter housings should preferably be pitched slightly toward a drain. The section of flooring between two banks of components must be considered a separate floor to be drained independently. Floors should be free of obstructions and raised items that would be hazardous to workmen. Concrete floors must be smooth and free of cracks and spalls, and tops of curbs must be pitched away from the steel to prevent corrosion from standing water.

4.5.7 Housing Doors

Easily opened doors are essential on large housings, and more than one door is generally needed. A door should be provided to each compartment (space between banks) where maintenance, testing, or inspection may take place. To save the cost of access doors by requiring a workman to gain access to the downstream side of a bank by crawling through a filter opening, as the inspector is required to do in Fig. 4.35, is poor economy and can result in cross contamination of the system, damage to installed filters, and injury to personnel. The use of bolted-on

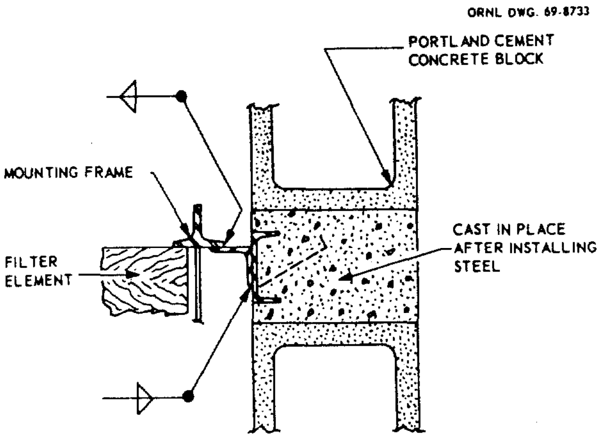

Fig. 4.34. Embedded structural member for walls and ceilings of masonry (shown) or concrete housing. Channel with flanges down is not suitable for floors, because trapped air would cause voids.

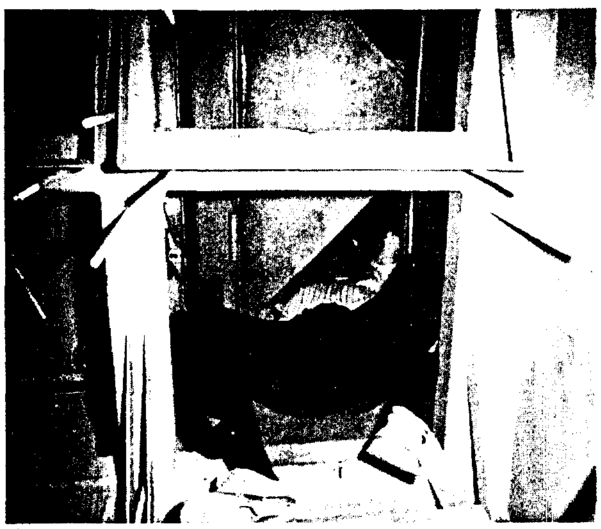

Fig. 4.35. Housing with inadequate provision for access. Inspector is required to crawl through a HEPA filter opening to gain access to downstream side of filters and to adsorbers.

removable panels for access to filter compartments should be avoided for even the smallest filter housings because of the time loss when necessary to get into the housing (the time loss could be disastrous in an emergency) and because nuts tend to rust or freeze after a few months of service. There is also the problem that lost nuts are often not replaced, which eventually results in reduced leaktightness of the panel. Sliding doors should never be used for filter housings, because they cannot be sealed and because they jam after any distortion of the housing.

Sturdy double-pin-hinged doors with rigid, close-fitting casings and positive latches, such as the marine bulkhead-type shown in Fig. 4.36, should be provided on man-entry housings, particularly those for ESF and other high-hazard service. Doors and gaskets must be designed to maintain a hermetic seal under positive and negative pressures equal to at least the fan cut-off pressure. Doors of negative pressure systems must open outward and, since they may have to be opened against the negative pressure, means for breaking the vacuum or for mechanically assisted opening are desirable. Doors should have heavy-duty hinges and positive latching devices operable from inside and outside. Means for locking, preferably a padlock, should be provided to prevent unauthorized entry. The stiffness of doors is important, since flexible doors can be sprung when opened against negative pressure or allowed to slam shut under load. An air lock at the entry to the housing will eliminate problems of opening doors against negative pressure and slamming, and also, if large enough, will provide an intermediate work area for personnel during a filter change.

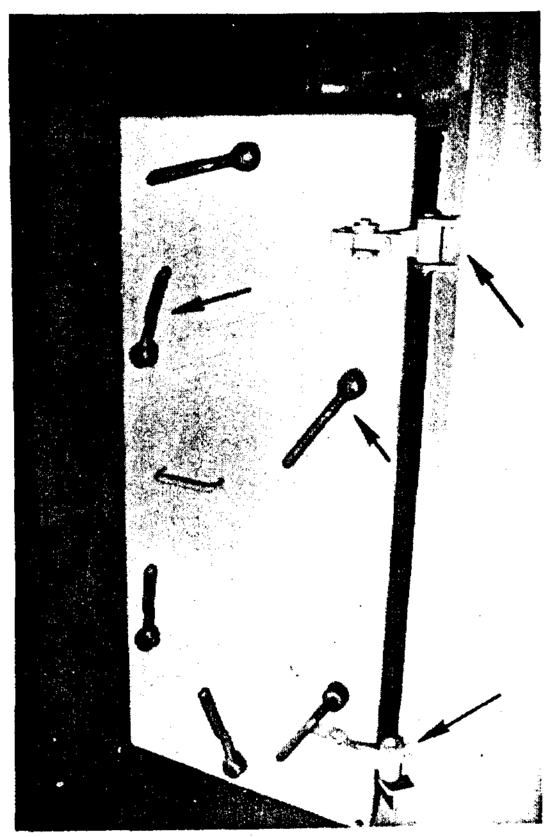

Fig. 4.36. Marine bulkhead-type housing door. Note rigid casing, slip-pin hinges, and latching dogs operable from both sides. The dogs at the top and bottom are probably unnecessary, since four would have been sufficient to seal a door this size.

Housing doors of the type shown in Fig. 4.36 require a minimum of two latching dogs on each side. Lighter-construction doors require additional latches to achieve a satisfactory seal. Latching dogs should be operable from inside and outside the housing, and shafts must be fitted with O-rings, glands, or stuffing boxes to prevent leakage. Door hinges should be of the double-pin, loose-pin, or other type that will permit the full plane of the door to move perpendicularly to the plane of the door frame during the last fraction of an inch of closure. Single-pin hinges, which result in angular motion throughout the door closing arc, do not permit the door to seal properly and may cause the gasket to be rolled out of its groove after a period of use, as shown in Fig. 4.37, thus resulting in the loss of housing leaktightness. If door gaskets are too hard they will be incompressible, and the door cannot be sealed properly even with lever-and-wedge latching dogs of the type shown in Fig. 4.36. If too soft, the gasket will rapidly take a compression set and lose its ability to seal. Solid neoprene or silicone rubber of about 30–40 Shore-A durometer is recommended.

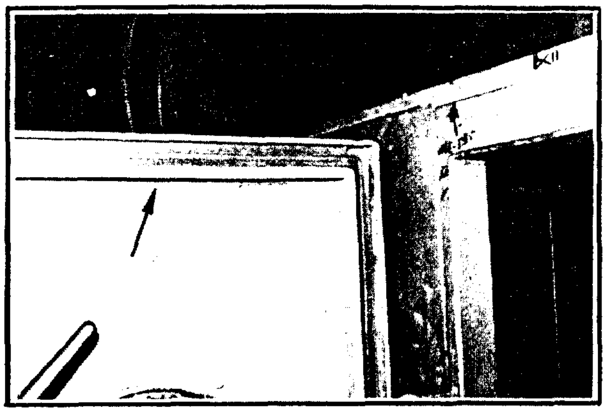

Fig. 4.37. Single-pin hinge causes gasket roll on hinge side of door. Door cannot be sealed.

A compromise may have to be made in sizing doors for man-entry housings. On the one hand, the door must be large enough for easy access to personnel dressed in bulky protective clothing, wearing gas masks or respirators, and perhaps carrying 24 × 24 × 12-in. filters weighing up to 40 lb, or 26 × 6 × 30-in. adsorber cells weighing up to 130 lb (dimensions of the door through which a 95th-percentile man can pass erect, carrying such loads, are shown in Fig. 4.38). On the other hand, the larger the door the more difficult it is to seal, and the more likely it or its frame can be damaged if allowed to slam under load. The door should be as large as possible for easy access, but in no event should it be any less than 26 in. wide by 48 in. high. A coaming (2 in. high minimum to 6 in. high

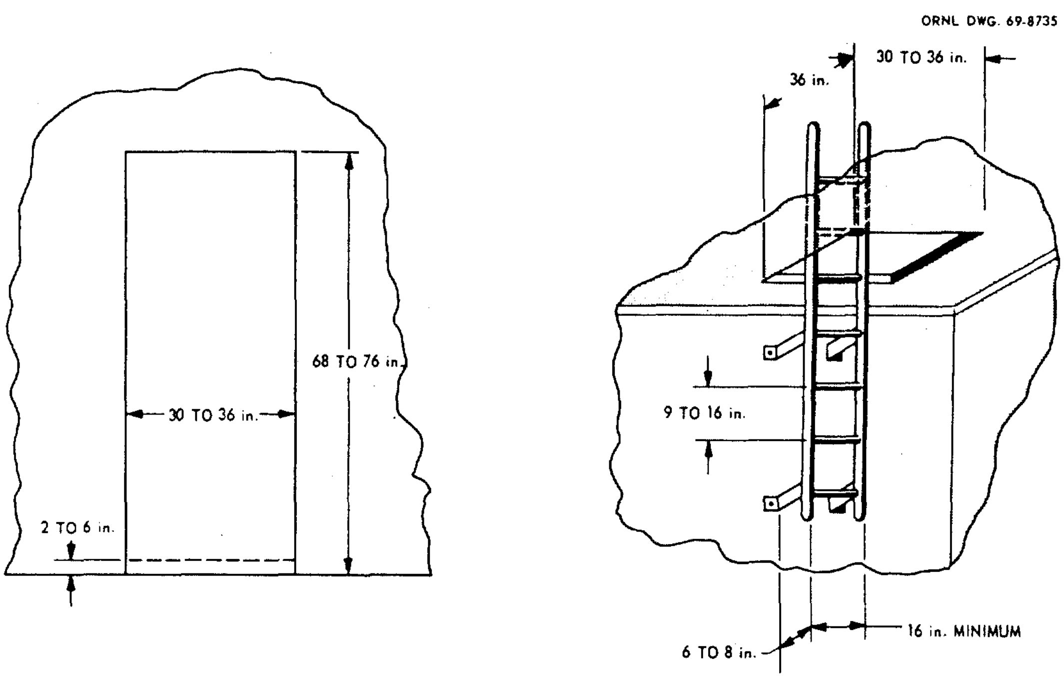

Fig. 4.38. Maximum filter-house door and hatch dimensions. Door dimensions based on erect 95th percentile man.

maximum) should be provided at all doors to prevent the outflow of contaminated water should the housing ever be flooded. The ladder and hatch dimensions shown in Fig. 4.38 are suggested for access hatches in work galleries, for high banks, and for hatches of underground filter pits.

4.5.8 Housing Drains

Floor drains are essential in contaminated-exhaust filter housings, particularly when sprinkler protection is provided. Even if moisture or condensation is not expected under normal conditions, occasional washdown may be required for decontamination, and water will be needed in the event of a fire. When the housing is above grade, the minimum provision for drainage is a Chicago half coupling, sealed with a bronze pipe plug, using tetrafluorethylene (TFE) plastic "ribbon dope" so the plug can be easily removed when needed. When the filter is at or below grade, drains should be piped to an underground contaminated-waste system during initial construction, since later installation is likely to be very costly. Drains from ESF systems must also be piped to the radioactive waste system. In cold climates, water seals, traps, and drain lines must be protected against freezing if they are above the frost line. When fire sprinklers are installed in the filter house, the drains must be sized to carry away the maximum sprinkler flow without water backup in the housing.

A separate drain is needed for each chamber of the filter house, and each drain must have its own water seal or trap. The spaces between two banks of components in series and between a bank and the housing are considered separate chambers. When piped to a common drain system, drain lines from the individual chambers of the housing must be valved, sealed, or otherwise protected to prevent bypassing of contaminated air around filters or adsorbers through the drain system.

4.5.9 Housing Leaktightness

Contaminated filter housings must be leaktight to prevent contamination of adjacent service and operating areas. Although it is commonly assumed that all leakage will be inleakage in a negative pressure system, outleakage can occur under some conditions, even when the system is operating at its design negative pressure, and particularly when the system is down. The recommended maximum permissible leak rates given in Table 4.5 are based on the criteria of the *Code of Federal Regulations* 10 CFR 20 and 10 CFR 100 and the current ALARA requirements. Leak testing of filter housings is covered in Chap. 8 and ANSI N510.[27]

Table 4.5. Recommended maximum permissible leak rates for contaminated exhaust and air cleanup filter housings ($\Delta p = 10$ in.wg)

Construction	Maximum permissible leak rate (percent housing volume per hour)
Unlined concrete	60
Painted concrete, masonry	30–36
Conventional sheet metal housing, no attention to doors, etc.	30–36
All-welded man-entry steel housing	0.2
Small single-filter housing	0.05
Housing of recirculating system located within containment building	Not critical
Boiling water reactor/gas cooled reactor containment	0.021
Pressurized water reactor containment	0.004

4.5.10 Other Housing Requirements

Figure 4.39 illustrates a number of features that are desirable in a contaminated exhaust or air cleaning housing. The housing is all-welded construction with No. 11 U.S. gage (~1/8 in.) walls and ceiling, 1/4-in. steel floor, and 3 × 3 × 1/4-in. reinforcing angles on 24-in. centers. The housing is one of six that were shop-fabricated for a series-parallel prefilter/HEPA filter installation for a high-hazard exhaust system at a research laboratory. Each housing contains either a bank of nine 1000-cfm prefilters or nine 1000-cfm HEPA filters. The housings are dampered as shown in Fig. 2.12. Features of the housing include

1. shop fabrication;
2. permanently installed DOP injection nozzles (inside housing) and probe and sample ports;
3. wired-glass viewports on each side of filter bank for visual inspection without entering the housing;
4. permanently installed lights on each side of filter bank, two in parallel on each side, with switch at

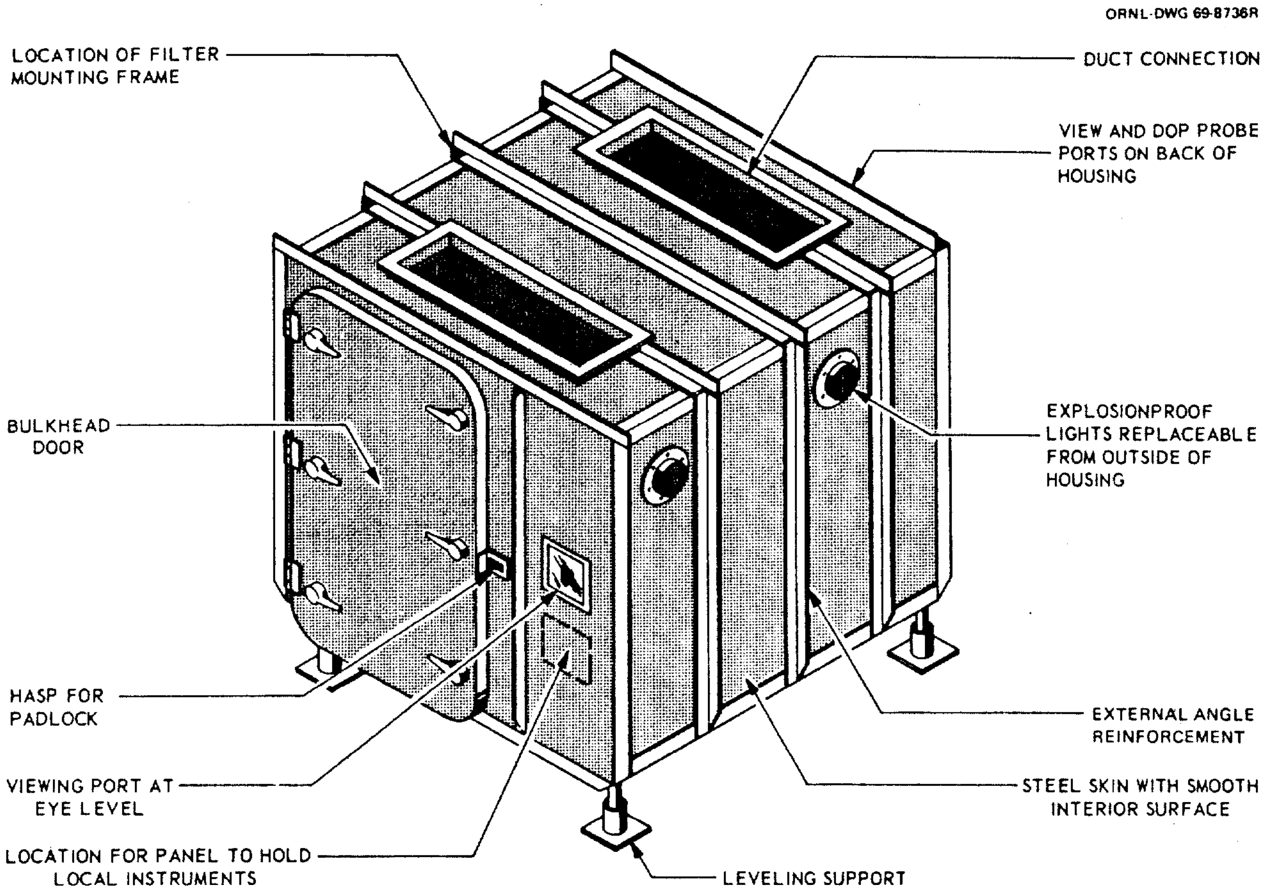

Fig. 4.39. Steel filter housing showing many desirable features.

door and second switch under viewport on back of housing; lights on independent switches;

5. lights installed in vapor-tight globes, replaceable from outside of the housing;
6. wiring installed on outside of the housing (penetrations for wiring are a common source of leakage);
7. shock-mounted instrument panel close to housing door, with pressure-drop manometer across each bank of filters;
8. large marine bulkhead door with dogs operable from inside and outside of the housing;
9. ample space (approximately 4 by 7 ft) inside of housing for personnel to work during a filter change;
10. all reinforcements on outside of housing;
11. housing opens on aisle that can be controlled and that serves as workspace during a filter change;
12. compartmented system—any housing of the six can be isolated for service or emergency without necessitating shutdown of system;
13. housing is isolated from the building, leveling feet for adjustment;
14. all-weld construction eliminates leaks to occupied areas.

4.5.11 Paints and Coatings

The mounting frame and housing interior of carbon steel and masonry must be painted to protect against corrosion and to facilitate cleaning and decontamination. Surfaces must be prepared properly, and prime and top coats must be applied in strict accordance with the paint manufacturer's directions in order to obtain the necessary wet-film and dry-film thicknesses. Film thicknesses should be tested during and after application. Steel surfaces should be abrasive-blasted to white metal to a profile of 1 to 2 mils in accordance with Surface Preparation Specification 5 of the Steel Structures Painting Council.[28] The prime coat must be applied within 2 to 3 hr after grit-blasting and in no case should be delayed to the next day. Hand- or power-tool cleaning (Surface Preparation Specifications 2 and 3 of the Steel Structures Painting Council) is usually sufficient for exterior steel surfaces. Ambient temperature and metal temperature should be at least 10 to 20°F above the dew point before starting to paint, and there must be adequate drying time between coats. Thick runs and streaks must be avoided, particularly on gasket seating surfaces, where they may chip off and leave uneven surfaces that will interfere with proper sealing of the filter. After painting, gasket seating surfaces should be coated with a silicone oil or grease to prevent the filter gasket from adhering to the paint after a period of service. Clamping bolts should not be painted because the paint will scrape off and jam the nuts. Threads should be masked during painting and then coated with a silicone grease.

High-build epoxy-polyamide or modified-phenolic coating systems have proven satisfactory for interior steel and masonry surfaces. Although inorganic zinc primers are often recommended for steel, their use is not recommended for housing interiors because the zinc particles are difficult to hold in suspension properly and they tend to surface, causing blistering and peeling of the top coats.[29] An airless spray is recommended for applying prime and top coats. Guidance in the selection of coatings and paints for nuclear service is given in ANSI N512.[30] For purposes of selection, the classification "moderate exposure" is recommended for high-activity (or potentially high-activity) systems, and the classification "light exposure" is recommended for low-activity systems. The recommendations on quality assurance during application of paints and coatings, given in ANSI N101.4,[31] are suggested for ESF and other high-activity (or potentially high-activity) systems.

Inorganic zinc primers are acceptable for exterior steel surfaces, but complete curing may take from two days to six weeks, depending on temperature and humidity conditions. One or two coats of high-build epoxy, vinyl, acrylic, or silicone paint are recommended for exterior steel surfaces exposed to the weather. Epoxy-polyamide coatings are superior to epoxy amines for water and salt resistance and have better tolerance for moisture during application. Vinyls are excellent for general marine and chemical plant exposures and do not chalk as much as the epoxies when exposed to sunlight. On the other hand, they are inferior to the epoxies in abrasion resistance, solvent resistance, and resistance to severe water or brine splashing. For out-of-doors service, acrylic coatings give the best protection against chalking and discoloration from sunlight and ultraviolet but are suitable only as top coats over an intermediate epoxy or vinyl coating. Silicone-base paints are useful for high-temperature applications, and aluminum-filled silicones give good protection up to 1000°F. For a housing or duct that is located indoors and is exposed only to normal building atmospheres, an acrylic paint is suitable and gives good protection against color fading.

Because of difficulties in applying high-quality coatings and their often unsatisfactory performance in service, the designer should seriously consider stainless steel for mounting frames and housing in applications where corrosion or frequent decontamination will be encountered. Although quoted prices for carbon steel construction with high-quality coating systems generally run about 20 to 25% of the cost of stainless steel construction, experience shows that delays and difficulties in proper application often raise the final cost of coated carbon steel to as much as or more than stainless steel.

REFERENCES FOR CHAP. 4

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6. ASTM A479, *Specification for Stainless and Heat-Resisting Steel Bars and Shapes*, American Society for Testing and Materials, Philadelphia, current issue.

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